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BRITISH
MANUFACTURING INDUSTRIES.

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G. PHILLIPS BEVAN, F.G.S.

SHIP-BUILDING,
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1876.

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PREFACE.

The object of this series is to bring into one focus the leading features and present position of the most important industries of the kingdom, so as to enable the general reader to comprehend the enormous development that has taken place within the last twenty or thirty years. It is evident that the great increase in education throughout the country has tended largely to foster a simultaneous interest in technical knowledge, as evinced by the spread of Art and Science Schools, Trade Museums, International Exhibitions, &c.; and this fact is borne out by a perusal of the daily papers, in which the prominence given to every improvement in trade or machinery attests the desire of the reading public to know more about these matters. Here, however, the difficulty commences, for the only means of acquiring this information are from handbooks to the various manufactures (which are usually too minute in detail for general instruction), from trade journals and the reports of scientific societies; and to obtain and systematize these scattered details is a labour and a tax upon time and patience which comparatively few persons care to surmount. In these volumes all these facts are gathered together and presented in as readable a form as is compatible with accuracy and a freedom from superficiality; and though they do not lay claim to being a technical guide to each industry, the names of the contributors are a sufficient guarantee that they are a reliable and standard work of reference. Great stress is laid on the progressive developments of the manufactures, and the various applications to them of the collateral arts and sciences; the history of each is truly given, while present processes and recent inventions are succinctly described.

BRITISH
MANUFACTURING INDUSTRIES.

SHIP BUILDING.

By Capt. Bedford Pim, R.N., M.P.

Introduction.

Of all the British Industries, the one of the greatest national importance is unquestionably that of ship building. Indeed, it is not too much to say that shipping is Britannia's backbone; and that all her other industries depend for support mainly upon that backbone.

This fact has contributed, under Providence, more than anything else to the wonderful strength and prosperity of Old England; and although it cannot be denied that "dry rot" is just now showing itself, yet a timely removal of the infected parts (a matter easily accomplished) will speedily restore its wonted durability to the stout frame, and enable Britannia to brave and overcome at least as effectually as of yore any tempest that may be destined to overtake her in future years.

In plain English, it is impossible to exaggerate the importance to Great Britain of her shipping, and consequently of ship building; indeed her very existence depends on the way in which this "industry" is dealt with. It is recorded of Alexander of Macedon, more than 2200 years ago, that he first laid down the principle that "the command of the sea ensures the possession of the land." Two hundred years later, the great Roman orator and statesman proved how well he understood the value of the sovereignty of the seas by such words as these: "*Qui teneat mare, eum necesse est rerum potiri.*" Nearer our own time, the words of Cicero were thus paraphrased by an illustrious English sailor, Sir Walter Raleigh: "He who commands the sea commands the trade of the world; and he who commands the trade of the world commands the riches of the world, and consequently the world itself."

The sentiment enshrined in the words of the Macedonian, the Roman, and the great but hapless Englishman, is expressed in the present day after the following fashion, "Britannia rules the waves." The moment this ceases to be the case, the downfall of England becomes merely a question of time; and for this very simple reason, that the produce obtained from the cultivated area of the kingdom is altogether insufficient to supply even a third of the population with the commonest necessaries of life; and having lost the command of the sea, having ceased to "rule the waves," with internal discord rampant amongst a divided, furious, and starving population, England can be blockaded and cut off from her food supply with as much certainty as Metz or Paris, leading to a result not difficult for the most thoughtless to foresee—unconditional surrender.

To keep open the approaches to our island home is a matter of paramount necessity; to do this we must have ships, merchant ships as well as fighting ships: the art of ship building therefore ought to take the first rank among British industries, and its practice should be encouraged in every possible way. Would that it were so!

We find architects rewarded for buildings of questionable taste and undoubted discomfort; but Englishmen do not seem even to care who designs the structure upon which their very being depends.

It is not proposed on the present occasion to devote the limited space at command to a lengthened dissertation on the practical application of the art of ship building: but rather to bring under one point of view the principles which should guide the art, and also the present position of this the first of national industries, and thus to give the student a zest for closer investigation; in fact, to create in him a true interest in his craft—a feeling more likely than any other to promote its real and permanent progress.

Sir John Brown plagiarised a saying of Bacon when he attributed his success in increasing the size and efficiency of iron plates from the supposed maximum of 4½ inches in thickness to 20 inches, to "working by the rule of thumb, finding out from day to day the way to accomplish his desire."

It is even so with the history of ship building. The successful ship builder has intelligently carried out the experience of centuries, gained by a patient working at the rule of thumb, judiciously applying practical knowledge and skill to the development of his art, theories to the contrary notwithstanding.

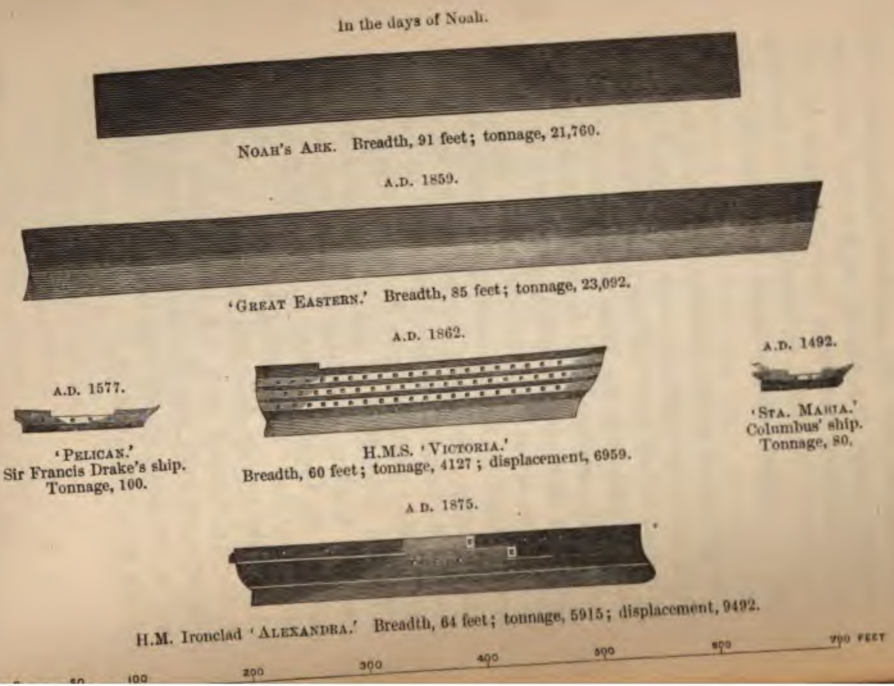
To this we may attribute the excellence to which ship building had attained some years ago, an excellence which has since suffered a palpable falling off, in so far at all events as regards the shape and good qualities of the hull of the ship.

That science has indirectly contributed towards perfecting the machine called a ship, no one will attempt to deny. But it is equally certain that the art of ship building has been indebted little by little during the last five thousand years for the various improvements which have marked its progress to the genius and intelligence of practical men, in spite rather than in consequence of so-called improvements, from time to time foisted upon it by outsiders in science. It would indeed be a hard task to name any given improvement, which has originated solely from pure abstract science.

The truth is, that the business of ship building is followed most successfully by those who weigh every so-called scientific *theory* by *practical experience* before adopting it; for after all, the really useful qualities of a ship mainly depend upon the practical experience of those who design and build her.

That is just the weak spot in our war ships; and the responsibility for the present unsatisfactory condition of the British Navy rests, and will continue to rest, on the naval authorities; solely because, instead of pursuing the safe and prudent course, they have utterly ignored the lessons of the past, and have blindly allowed themselves to be led away by self-constituted "oracles," absolutely without practical, and to a great extent without even theoretical, experience.

With respect to the shipping composing the merchant navy, here again the safe teachings of practice have been widely departed from; long, narrow vessels, reaching commonly ten times their beam, have been built, while empirical (not to say dishonest) tonnage laws have only too successfully performed their part in bringing about the deterioration of our ships; a fact made sufficiently notorious by the appalling losses which yearly take place, amounting to an annual average of about 1000 ships, from which no less than 4416 seamen and passengers were lost between July 1873, and June 1874, a serious increase since Mr. Augustus Creuze, a well-known naval architect and surveyor at Lloyd's, wrote in the 'Encyclopædia Britannica,' that "the startling fact that one ship and a half is the average daily loss registered on the books of Lloyd's, appears as a sad corroboration of the acknowledged truth, that the mercantile navy of England is the least speedy and the most unsafe that belongs to a civilized nation."


In the days of Noah.
NOAH'S ARK. Breadth, 91 feet; tonnage, 21,760.
A.D. 1859.
'GREAT EASTERN.' Breadth, 85 feet; tonnage, 23,092.
A.D. 1577.
'PELICAN.'
Sir Francis Drake's ship.
Tonnage, 100.
A.D. 1862.
H.M.S. 'VICTORIA.'
Breadth, 60 feet; tonnage, 4127; displacement, 6959.
A.D. 1492.
'STA. MARIA.'
Columbus' ship.
Tonnage, 80.
A D. 1875.
H.M. Ironclad 'ALEXANDRA.' Breadth, 64 feet; tonnage, 5915; displacement, 9492.
50
100
200
300
400
500
600
700 FEET

History.

Considerable attention has already been devoted to investigating the origin of ship building, and much research and great learning displayed; but it does not come within the scope of an essay to follow this course; every page would be absorbed in merely setting forth the probable manner in which primitive man, obeying the instinct implanted in him by the Great Creator, to "have dominion over the fish of the sea and the fowl of the air, and every living thing that moveth upon the face of the earth," first of all discerned that his body was sufficiently buoyant in water to float for a considerable time, and then found out how simple and easy a matter was swimming. The next discovery was, that a log of wood would keep him afloat without any effort of his own, and that when a few more logs were added and lashed together, a safe platform was created, upon which he could transport himself from point to point on river or sea. From the raft to the hollow trunk of a tree or the canoe is an easy step, from which naturally arose the built-up boat, enlarged from time to time as required, until at last it grew into a "tall shippe."

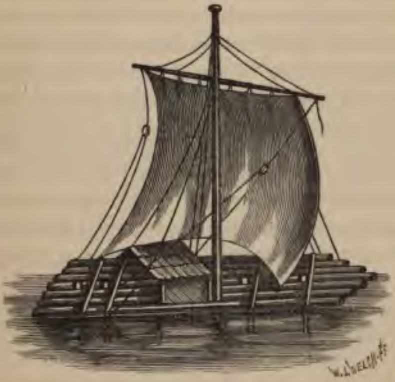
Any sketch of the rise and progress of ship building in the Old World, from the log of pre-historic man to the built boat, is of course conjectural; but the discovery of the New World enables us to form a correct idea of primitive naval architecture.

Columbus, writing on the 15th February, 1493, says that "the people of this island (Española) have many canoes propelled by oars, some of them large and others small, and many of them with eight or ten paddles of a side, not very wide, but all of one trunk, and a boat cannot keep way with them by oars, for they are incredibly fast. I have seen some of these canoes with sixty or eighty men in them, and each with a paddle."

To this day the New World possesses a rich diversity of aboriginal naval architecture of the primitive type, admirably adapted for the locality in which it is found, but nevertheless in no instance amounting to a built boat. The Esquimaux kayak is the nearest approach; the skeleton is built up of drift wood, whale and other bone, and then neatly covered with dressed skins; a round hole made in the centre admits the man's body, and in this frail craft he goes to sea in the roughest weather, in pursuit of white whale, seal, &c., &c.

The bark canoe of the North American Indian also deserves attention, from the amount of skill required in its construction and management. For river or lake navigation, the lightest material is needed, and no primitive ingenuity could have hit upon anything better adapted than the bark of a tree for the purposes required.

The canoe of Vancouver's Island is perhaps the finest for its size, beautiful shape, speed, and seaworthy qualities; but beyond question, the balza or raft of Colombia displays in the highest degree the ingenuity of primitive man; so excellent is the method employed to steer these rafts, that it is surprising that it has not been copied nearer home, tens of thousands of lives might have been saved by the adoption of this simple contrivance. The following account of the balza is taken from an old Spanish narrative of a voyage to South America in 1745:



BALZA.

"These jangadas or rafts are called balzas, from Balza, the name of the tree of which they are made. They consist of five, seven, or nine logs, by the Darien Indians called Puero. The balza is a whitish spongy wood, and so very light that a boy can easily carry a log four yards long and a foot in diameter.

"The puero trees of which the balzas are built are twelve or thirteen toises long, reckoning five feet to the toise, and two feet or two and a half feet diameter; so that the whole breadth of nine logs, of which some of them consist, is between twenty and twenty-four feet; and those of seven or fewer logs are proportionate.

"These logs are fastened to each other only by the bejucos or withies, with which the cross logs also are lashed to them; yet so securely as never to give way if not worn out by long use; though in their voyage to the coast of Tumbez and Payta the sea runs very high. . . .

"These rafts work and ply to windward like a keeled vessel, and keep their course before the wind almost as exactly, which is the effect of another contrivance besides the rudder: some large planks, three or four yards long and half a yard broad, called guares, are set up vertically at the stern, and also forward between the main logs. By pushing some of these under the water and taking others a little up, the float sails large, bears up, tacks, or lies to, according as the machine is worked; an invention which has hitherto escaped the acuteness of the most ingenious Europeans; and though the Indians have indeed contrived the instrument, yet they are utter strangers to the principles of mechanics, and the causes of its operations.

"Had it been known before in Europe, the loss of many lives in shipwreck might have been prevented, as appears by the following among many other instances: in the year 1730, the 'Genouesa' ship of war being lost in the Vivora, the mariners made a jangada or raft to save their lives, but miscarried by committing themselves to the winds and currents without any steerage; and the frequency of such melancholy events induces me to give a minute explanation of this instrument from a memoir of Don Jorge Juan relating to it."

Captain Basil Hall says that a balza, such as described above, worked to windward of H.M.S. 'Conway,' under his command.

However much we may admire the clever adaptation of the means at their disposal to the exigencies of the locality in which they resided, it seems certain that at the time of the discovery of America, the aborigines had nowhere on the continent arrived at the art of building up a vessel, and this can be readily accounted for by the fact that the requirements of the people, so far as fishing transit and traffic were concerned, were amply met by the simple contrivances of the kayak, canoe, or balza, in their respective localities. Navigation, in the broad sense of the word, was unknown; there was in short no necessity for venturing out of sight of land; and without such a stimulus it is not to be wondered at, that no advance in the art of ship building had been made in the New World.

To return to the Old World. The first record we have of a built vessel is found in that Book of books the Bible, at a period dating backwards more than four thousand years. Noah's Ark is thus described in Gen. vi. 14–16:

> "Make thee an ark of gopher wood; rooms shalt thou make in the ark, and shalt pitch it within and without with pitch. And this is the fashion which thou shalt make it of: The length of the ark shall be three hundred cubits,* the breadth of it fifty cubits, and the height of it thirty cubits. A window shalt thou make to the ark, and in a cubit shalt thou finish it above; and the door of the ark shalt thou set in the side thereof; with lower, second, and third stories shalt thou make it."

It is not a little curious that the word תֵּבָת (Ark) occurs only once again in the Hebrew Bible, Exod.

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* The exact length of the cubit is questioned to this day. Newton places it at 20·625 inches, while Wilkins considers it to be more than an inch longer, viz. 21·88 inches. The measure with the Jews was that of the forearm, and may have been more or less than that of mankind at the present day, for all we know to the contrary.

ii. 3, about 3500 years ago. In both instances the term is used to designate a vessel for saving life; its etymology however is unknown.

In the case of Noah's Ark, the dimensions are singularly near to those found in practice as well suited to vessels destined for service in *smooth* water, viz. six times the beam for length and one-tenth of the length for depth.

It is mentioned by German commentators, that Peter Jansen in 1609 built a vessel of the same proportions as the Ark, though smaller, viz. length, 120 feet; width, 20 feet; depth, 12 feet. It was found most convenient for stowage, containing one-third more freight than ordinary vessels of the same tonnage, though it was unsuited for making way quickly through the water.

Later still, in our own time (1855), Captain Peacock, R.N., built an iron ship, of which he says:

> "She was 180 feet between the perpendiculars, 30 feet beam, and 18 feet deep; that is, six times the beam for length, and one-tenth of the length for depth: 200 feet over all, including cut-water and overhang aft; she was perfectly flat on the inner floor or ceiling, the rise being one inch to the half breadth on fifteen inches, which was the depth of keel, the top angle irons tapering off to nothing at the sudden turn of the bilge; half an inch in the foot for beam, the ends forward and aft very sharp. The upper deck beams were braced with ⅝-inch plates running fore and aft amidships 2 feet wide, and a series of diagonal plates, 9 inches wide, crossing each other, the end being riveted to the wing shelf plates, and all riveted to the beam angle irons, at the crossings, and to the midship bracing plates. She had iron masts and iron lower yards, also iron bowsprit, all fitted for venti-

lating. The ship turned out a good one, and sailed remarkably well; she has been in the New Zealand trade ever since (twenty years), and is still running, sound and good as on the first day she was built. The bottom has always been kept coated with Peacock and Buchan's composition, and the cabins, between decks, topsides, boats, &c., with the No. 3 composition, which has been proved to be the best composition for ships' bottoms during the same lengthened period on board H.M.S. 'Himalaya.'"

After the Flood, B.C. 2384, we may assume that ship building extended itself to all parts of the known world. The Greeks, the most ancient of European nations, who date their history as far back as the eighteenth century B.C., paid great attention to ship building; but even with this wonderful people, progress in the art was necessarily slow, and many a century passed away before their vessels reached beyond the rank of row-boats, even that very doubtful craft the ship 'Argo,' B.C. 1263, canonized as a constellation, has never been described otherwise than as a large vessel propelled by fifty oars. Through the whole of Solomon's reign, B.C. 1015–975, this style of build continued, and it is not until about B.C. 588 that we arrive at the first distinct mention of a sailing vessel, as alluded to in Ezek. xxvii. 7: "Fine linen with broidered work from Egypt was that which thou spreadest forth to be thy *sail*." But even from this period until the Christian era, the progress in the art of ship building continued to be very slow, the compass was still unknown, even the rudder had not been invented; while the principal motive power was undoubtedly the oar, made of oak, a heavy, cumbersome, and uncertain mode of propulsion, capable of application for even moderate distances only by forced labour. It is not to be wondered at therefore that the ancients never ventured out of sight of land; and as they were consequently unacquainted with the art of navigation, the type of vessel suited for coast service remained unaltered from age to age.

The Greeks undoubtedly carried off the palm in the ship building of that day, their galleys for beauty of form and speed were then unequalled. They were also the best sailors, and to this hour retain that character in the Mediterranean.

Some description of the galley, erroneously called the Roman galley (obviously a copy of that of the Greeks, used by that wonderful people, a thousand years before the Romans had a national existence), may not be uninteresting; as, after all, it is the type of vessel which, for so many ages, maintained a proud pre-eminence amongst the nations of antiquity.

In very early times the galley was little better than an open boat; indeed, even so late as the battle of Salamis, B.C. 480, Plutarch states that the largest Grecian vessel carried only eighteen soldiers, exclusive of the rowers and sailors. But, little by little, improvements were effected, such as beams, gunwales, and ultimately decks, invented by Cimon about B.C. 450. The galleys consisted of biremes, triremes, quadriremes, up to octoremes; while some have had the hardihood to declare, that a ship has been built with forty banks of oars.

About the meaning of the term *reme* there has been much learned disputation, unsettled to this day. It is gravely asserted that the rowers were placed in rows or tiers above each other, and the great effort on which much ingenuity has been displayed, seems to be to account for this impossible state of affairs, instead of overthrowing it altogether. For, to take the extreme case, the octoreme, it is quite clear the rowers must have required not less than 4 feet headroom for each row, or at least 4 feet from the water line, necessitating a length of oar even to touch the water (supposing the rowers to keep hold of the loom) of more than 60 feet in length—how worked no one can tell. The confusion may have arisen from some mistake of the translator, through not understanding nautical terms; indeed, the following rather curious instance of incorrect translation strengthens this surmise. In a description of Ptolemy's ship still extant, the trans-

A GALLEY.

lator mentions amongst other wonderful circumstances that the ship was furnished with fountains, gardens, and theatre, and *four markets*—the words "*quatuor foros*," meaning *four decks*, having been mistaken for the plural of *forum*, a market! The term probably refers to the number of rowers at each oar, and not to the number of tiers of rowers; thus a bireme would have two men at the oar, or, to use a common expression, the oar would be "double *banked*," a trireme three men, triple *banked*, and so on. And this idea is strengthened by the fact that the galley increased in length in proportion to the number of its rowers: thus a bireme was 90 by 10, with two men on each side (she would have capsized with two tiers of rowers): trireme 125 by 13, with three men on each side; quadrireme 300 by 35, with eight men on a side; in which case, if the banks or tiers had been above each other, then the centre of gravity of the octoreme would have been more than 30 feet above the water line, and therefore her proper position in the water would have been bottom upmost.

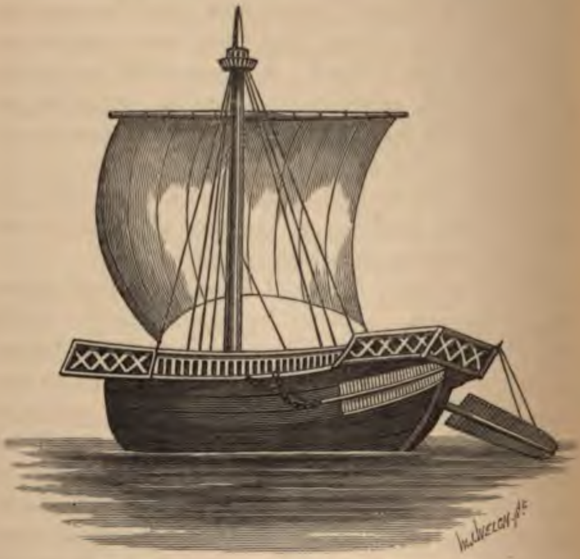
Whatever may be the worth of the idea sketched out above, it is thrown out for the thoughtful consideration of the learned in these antiquarian researches; but it may be added, that it is at all events singular that no Egyptian, Assyrian, Greek, or Roman monument represents a galley of more than one or at most two tiers of oars. It is true that a Roman painting found in the Orti Farnesini gives a galley with three tiers, but hitherto no authentic record of a galley with more than one tier of oars has been found.

The next step in ship building is from the galley to the sailing vessel.

As commerce extended, it was soon discovered that little dependence could be placed on the row galleys for carrying freight. In the first place, the space for cargo was very limited, and there were other objections of no less moment. A larger vessel, a vessel of burden in fact, naturally came into use, wafted on her course by sail power, although in some instances still fitted with a few oars for calms, just as some of the vessels in the Spanish Armada, and, later still, the brigs of war employed on the coast of Africa in our own time, are supplied with sweeps.

The description of one of these vessels will suffice for all the rest. Take for instance the ship in which St. Paul voyaged from Myra to Malta; this famous vessel was wrecked in the first century of our era, A.D. 70. The size of ancient sailing ships was by no means inconsiderable; of course there were small and large, a coaster, for example, such as the vessel of Adramyttium, which carried St. Paul from Cæsarea to Myra; and vessels of at least 500 tons, such as those engaged in the Alexandrian wheat trade, in one of which he was wrecked.

The ships of that day had only one mast, upon which was hoisted by means of large heavy gear a huge square sail. With such a lever, it is no wonder that they tore themselves to pieces in a heavy sea, opening their seams, leaking, and often foundering. To remedy this defect "under girders" were used; they were simply stout ropes passed round the ship athwart-ships and set taut on deck, thus keeping the vessel together. The same plan is adopted to this day, when a ship has been severely strained in heavy weather.



A SAILING SHIP, A.D. 70.

The rudder had not then been invented, nor indeed was the idea of hanging a "steering oar" to the sternpost thought of; at least there is not a trace of any such invention to be found for more than a thousand years after St. Paul's shipwreck. The steering apparatus was but a huge oar thrust through a sort of hawse pipe on each quarter; and, when not in use, these oars were no doubt triced up to the ship's side. This seems to have been the case during the fourteen days St. Paul's ship was drifting from Clauda to Malta, for it is expressly stated in the narrative, that when preparations were made to run her on shore, the rudder "bands (or tackles) were loosed," no doubt in order to steer the ship into the "certain creek." Thus it will be seen that the sailing ships of the ancients, although unquestionably primitive, were by no means to be despised; and when managed by skilful shipmen, in possession of good charts, fully answered the requirements of the commerce of that age. They could beat to windward, and were able to sail seven or eight knots an hour with the wind at all favourable, and no doubt carried a heavy cargo.

The earliest record of charts constructed for "shipmen" is about A.D. 150. One Marinas, of Tyre, seems to have been the father of hydrographers; but, no doubt, rude delineations of coast line were in use on board ship long before his time. Even the Esquimaux, when visited by Parry in 1820, were found sufficiently intelligent to sketch the outline of the land some considerable distance from their habitations; how very unlikely then, that the highly civilized ancients were unacquainted with cosmography centuries before the period when Marinas flourished.

The history of the rudder is very similar to that of the mariner's compass, and is another instance of how closely the progress of navigation is connected with that of ship building. Indeed, the invention of a nautical instrument like the compass was just the very stimulus needed to develop the ancient steering paddle (which had answered the mariner's purpose admirably for 3000 years, whilst his navigation was confined to creeping along shore) into the hanging rudder. This, however, became a necessity as soon as ships ventured boldly out on the ocean; for no crew would have the physical endurance to steer by manual labour day and night, in all weathers, by the paddle only; in fact ships under certain circumstances, such for example as scudding before a strong wind, would be simply unmanageable by paddles alone.

There is no record of the actual inventor of the rudder, any more than of the mariner's compass. The earliest authentic notice is that on the seal of the city of Damme, A.D. 1328. This seal contains the picture of a ship, at the stern of which is the rudder with pintle and gudgeon, a tiller over the rudder head. In England its use cannot be traced with certainty earlier than about the middle of Edward III.'s reign, A.D. 1350. But there are manuscripts of a much later date in which ships are drawn steered by the paddle, so that doubtless many years elapsed before the rudder came into general use. It was probably not until the close of the fourteenth century that the rude seamen of that period were familiar with it. It is remarkable that exactly the same manner of hanging the rudder by pintle and gudgeon, as is shown in the seal of Damme is still in common use 550 years later.

For more than 1000 years, St. Paul's ship continued to be the type of vessels employed in carrying the commerce of the world. Some improvements may indeed be mentioned in regard to the rigging, and in the use of additional masts, which, by distributing the strain, obviated in some measure the necessity of under girding; but beyond this no decided step in advance, conducive to either speed, safety, or seaworthiness can be mentioned. A new era, however, was about to dawn on seafaring matters, destined to give a greater impetus to ship building than it had ever before received. The well-known property of magnetic iron ore was discovered to be applicable as an unerring guide for vessels on the ocean; and hence the invention of the mariner's compass, without which, humanly speaking, ships must have continued, century after century, fashioned very much in the same manner as they had been for the preceding 2000 years.

The invention of the mariner's compass and the rudder, about the beginning of the fourteenth century, forms perhaps the most important chronological pivot in the history of ship building. It would have been as absurd to attempt to make a long sea voyage without a rudder as without a compass; but the latter once obtained, there was an unerring guide by day and by night, in storm, sunshine, and fog.

There has been much controversy as to the date of this invention. Flavis Gioja, a native of Amalfi, is asserted by the Italians to have been the inventor, A.D. 1300 or 1320. He may have effected great improvements in the compass as a nautical instrument, but it had been used at sea off the Syrian coast several years before, as related by Baïlak Kibdjake, who describes it in the following terms:

"The captains who navigate the Syrian sea, when the night is so dark as to conceal from view the stars, which might direct their course according to the position of the four cardinal points, take a basin full of water, which they shelter from the wind, by placing it in the interior of the vessel, they then drive a needle into a wooden peg or a cornstalk, so as to form the shape of a cross, and throw it into the basin of water prepared for the purpose, on the surface of which it floats. They afterwards take a loadstone of sufficient size to fill the palm of the hand, or even smaller, bring it to the surface of the water, give to their hands a rotatory motion towards the right, so that the needle turns on the water's surface; they then suddenly and quickly withdraw their hands, when the two points of the needle face north and south. They have given me ocular demonstration of this process during our sea voyage from Syria to Alexandria, in the year 640" of the Hegira = A.D. 1262.

If further proof were needed that there is nothing new under the sun, this would be found in "the latest" improvement, the liquid compass, which would seem to be only a copy of that described above; except in so far, that it is dressed in a better garb than the primitive basin of 600 years ago.

The invention of the mariner's compass must not, however, be confounded with the discovery of the directive power of the loadstone, known in mineralogy as a magnetic iron ore, which consists of one equivalent of protoxide and one equivalent of sesquioxide of iron (Fe[illegible] Its attracting power was known at a very early period; indeed there seem good grounds for supposing that the Chinese were aware of this property more than 2000 years B.C.

This attractive power is also mentioned by Homer, B.C. 950; Aristotle, B.C. 340; and still more particularly by Pliny, A.D. 70, who speaks of the ignorant calling it *Ferrum vivum*, or "quick iron."

Thus it will be seen that more than 3000 years elapsed from the discovery of the property of certain iron ore, as a sure means of keeping a ship's head in the desired direction, before the immense value of that property was realized and applied to a practical use, unequalled by any other agent of Providence in advancing the civilization of the world. The whole face of seafaring matters changed; the "shipmen" from being little better than serfs, hardy and brave it is true, but still of the lowest order, became "seamen" in the true sense of the word. The whole globe was thrown open to their daring enterprise; while the ships themselves, as practical experience enlarged, steadily improved in all those qualities which constitute a seaworthy vessel.

The doubling of the Cape of Good Hope (dismally named Cabo Tormentoso by Vasco de Gama, in 1497), and the discovery of the New World sufficiently attest the rapid strides made in less than a century in the excellence of the seamen and the good qualities of the ships. All Europe entered on the race, and the palm was, sometimes with one, sometimes with another. For instance, it was for long considered, that only the Portuguese could build ships capable of withstanding the huge waves met with in rounding the Cape. Then the ships of the Spaniards became the favourites, until the signal defeat of the "Invincible Armada" (1588), in which were many ships of the clumsiest and most unwieldy build. The English then became undisputed masters of the art, until the French proved the superiority of their ships, which superiority they have consistently endeavoured to maintain to the present time. In respect to our English ships of to-day, there is vast room for improvement, both in the navy and mercantile marine.

The startling fact that *three* ships is the average *daily* loss registered at Lloyd's corroborates the humiliating truth, that the mercantile marine of England is less safe and seaworthy than that of any other civilized nation; while, in respect to the royal navy, the fact that the casualties of late years number *four* more than those to the war ships of all the Continental Powers put together, leads to the natural inference that its state and condition is scarcely less discreditable than that of the merchant shipping.

At the end of the Great War, our mercantile marine numbered 21,000 ships, of an aggregate tonnage of 2,200,000—more than was then possessed by all Europe. But in 1874, while our ships numbered 24,828, with a tonnage amounting to 5,912,314, European tonnage far exceeded ours; indeed, Free Trade has made such rapid inroads, that even in our home ports in 1870, of the total tonnage (36,640,182) entered and cleared, 11,568,002 was foreign. Instead of doing the carrying trade of the world, we have now little more than two-thirds of our own. Indeed, our merchants themselves find it to their interest to employ foreign ships very largely. This depreciation would have been felt to a much greater extent had not the American civil war almost swept the shipping of our most formidable rival from the sea.

During the last century there was doubtless some improvement in our shipping, but the present century has witnessed greater changes than ever took place previously. These changes were brought about by the introduction of iron into ship building, and the application of steam power as a mode of propulsion.

At the time these changes began to take effect, soon after the first quarter of this century, the English merchant ship was no doubt in advance of the "clumbungays" employed during the Great War.

Among the ships of the royal navy some beautiful models and very efficient ships were to be found; headed, however, it must be confessed, by the 'Canopus,' a captured French two-decker, which exceeded every English ship in speed, steadiness, and efficiency, as a man-of-war. In the merchant service it is only necessary to mention the fine frigate-built ships of Messrs. Green, and other firms, creditable alike to owners and builders, and in which a seaman could and did take an honest pride.

To a great extent this is now altered by the revolution effected by steam, a change which has made its mark, not only on the ships, but upon the seamen themselves. The keen competition of the present day has in only too many cases eliminated all considerations for the seaworthiness of the ship, if such considerations call for the expenditure of one shilling more than the absolute necessities of the venture demand, and hence the long, narrow "coffins" built by "the mile" as the saying is; while in respect to the seamen, the mongrel crews of unshipworthy men which nowadays disgrace our merchant ships, form a serious blot on the escutcheon of the nation. The true sailor is habituated to constant vigilance, and the exercise of the best intelligence at his command, while the so-called seamen of to-day, both officers and men, seem to have lost all the cunning of the craft, and to carry on their business almost as mechanically as the engines which drive their ship. The British sailor has always been proverbial for his thoughtlessness, and in this respect, and this only, he has remained unaltered by those most revolutionary of all revolutionary agents—steam and free trade.

An attempt has now been made to trace the history of the rise and progress of shipping step by step, at such length as the limited space at command would allow; from the earliest period at which any light can be thrown on the subject, when indeed little but conjecture is to be found to guide the student in his studies, up to the present day, when we find the sea covered with ships, good, bad, and indifferent, and nations vying with each other in the great race of competition, straining every nerve to possess the most efficient form of war ship for effecting the destruction of any rival with which it may come in conflict.

It has been mentioned above, that considerable changes have taken place in this great British industry, ship building, by the substitution of iron for wood, and it may not here be out of place to give some account of the rise and progress of the employment of iron in ship building.

Iron seems to have been brought into use in 1787 in the construction of canal barges. The first was 70 × 6 × 8½; plates $\frac{5}{16}$ riveted; stem, sternpost, and beams, wood; gunwale lined with the same. She displaced about 8 tons, drawing 8 to 9 inches when light: she carried when fully loaded 32 tons.

The first iron steam vessel that ever went to sea was the 'Aaron Manby,' built under a patent taken out in France, in 1820, by C. Manby, Esq. (present Honorary Secretary to the Institute C.E.), and the late Admiral Sir Charles Napier, who navigated her from London to Havre and thence to Paris, without unloading any part of her cargo of linseed and iron castings. From 1822 to 1830 the 'Aaron Manby' required no repairs to her hull, although repeatedly on shore with a full cargo.

In 1824 Mr. Grantham, the well-known engineer, had an iron steamer called the 'Marquis of Wellesley' on Lough Derg on the Shannon. She was a twin boat, having a paddle-wheel in the centre, very similar to the present Channel steamer the 'Castalia.' In 1834, the 'Garry Owen' was built by Mr. John Laird: she was fitted with water-tight bulkheads, the invention of Mr. C. W. Williams.

From this period the building of iron steamers and sailing vessels has steadily increased, culminating, as far as size is concerned, in the 'Leviathan,' now called the 'Great Eastern.' She was commenced in 1853, and finished four years afterwards (see Frontispiece). Her dimensions are: between perpendiculars, 680 feet; upper deck, 692 feet; beam, 83 feet; and, including paddle-boxes, 118 feet; displacement at launching, 10,000 to 12,000 tons; when fully laden, 25,000 tons at a draught of 30 feet. There is no keel, but a very flat floor; her bottom, up to a few feet above the water line, is double or cellular, the space between amounting to 34 inches; besides which, two longitudinal or wing passage bulkheads run fore and aft for about half her length, a substantial protection to boilers and engines. This proved on one occasion her salvation, for having touched the ground, the damage was found to be most extensive, while the repairs effected in New York were useless; the 'Great Eastern,' however, returned to England with a big hole in her side with perfect safety.

Iron has no doubt played and now plays a considerable part in ship building interests, but a greater revolution has been effected by the use of steam.

The introduction of steam as a motive power on board ship may be dated from the beginning of this century, but its expansive power was well known 2000 years ago. Hero of Alexandria (B.C. 100), in his 'Pneumatics,' describes various methods of using steam as a power. And Roger Bacon, the father of English Philosophy, born A.D. 1214, seems to have alluded to the uses to which its properties might be adapted in his 'Opus Magnus.'

Some idea of the expansive power of steam may be gathered from the fact, that 1 cubic inch of water occupies 1711 cubic inches of space in a temperature of 212°.

For the credit of having invented the steam engine there have been many claimants; but the slow growth of the invention renders it almost impossible to name any individual as the actual inventor. This much may at all events be conceded, that almost every country has done something towards rearing the infant phenomenon and bringing it to its present colossal proportions. England has most certainly not been behind other nations in this respect, and she may justly claim a large share of the glory individually. The Marquis of Worcester (1663), Savery (1698), Newcomen (1705), and Watt (1781), have made their names household words in connection with the steam engine.

With respect to the application of steam on board ship as a motive power, the earliest mention of an attempt to move a vessel by steam is said to exist in the archives of Simancas, under date 1543. The experiment was made with a vessel called the 'Trinidad,' of 200 tons, by the inventor, Don Blasco de Garay, who appears to have succeeded so far as to move the 'Trinidad' at the rate of three miles an hour; the usual jealousies, however, proved an insurmountable bar, and prevented the inventor from prosecuting his invention.

Two hundred years later, Jonathan Hull took out a patent (21st December, 1736), and to him is due the credit of giving birth to the idea of steam navigation in England. He proposed to propel vessels by a wheel over the stern, and to employ those vessels for towing purposes.

At the same time that Jonathan Hull was patenting his invention, other minds were converging to the same point — Messrs. Bernoulli, Bouguer, Euler, Mathieu de la Cour, and others; but practically the steam engine had not yet arrived at sufficient perfection to be conveniently applied to the purposes of navigation, and it was not until 1781, in the hands of Watt, that this was accomplished. Even then, seven years passed away before experiments both in Europe and America were made, which conclusively proved the adaptability of the steam engine as a motive power on board ship.

Space will not permit a detailed history of the progress of steam navigation step by step. At the beginning of this century, the fact was established that steam could be used advantageously for towing vessels in canals and smooth water, the propelling power employed in the first instance being a wheel at the stern of the towing boat, afterwards shifted, made to revolve on each side, and called paddle-wheels.

Little by little, improvements were introduced in the machinery; little by little, fresh confidence was gained in the seaworthiness of a steam vessel, until at last the new invention was thoroughly established.

The first person who ventured to take a steamboat to sea was Stevens, of Hoboken. Stevens had to take his vessel from New York to the Delaware (1807) in order to bring her into notice at all, as Fulton had obtained the monopoly of steam navigation on the Hudson.

The first steamboat, laid down and built with a set purpose in England, was the 'Comet,' in 1811. She was 40 by 10½ feet, of about 25 tons burden, and 3 horse-power; she ran between Glasgow and Helensburg at the rate of about five miles an hour. At the same time, a vessel was building in Ireland of rather larger dimensions; singularly enough she also was called the 'Comet,' and, strange to say, the first steamer built for the navy bore the same name.

By the year 1815, steamboats were plying on all the great rivers of England, as well as on the Seine, and between Seville and San Lucar. To the enterprise of Mr. Bell, a house carpenter, of Glasgow, is due the credit of building the above mentioned 'Comet,' the first steamer on the Clyde, and from that time the fortune of steam navigation steadily progressed.

In 1818, the following steamers were plying in the United Kingdom: eighteen on the Clyde, two at Dundee, two on the Tay, two on the Trent, two on the Tyne, four on the Humber, two on the Mersey, three on the Yare, one on the Avon, one on the Severn, one on the Orwell, six on the Forth, one at Cork, two intended to navigate between Dublin and Holyhead, and nine on the Thames.

At the same time, steam vessels were in use in Russia, the Netherlands, France, and Spain, and one was building in the East Indies; while in the United States every important route was occupied by steamers, those on the Mississippi alone being 450 tons, carrying 280 tons of merchandise, 100 passengers, and 700 bales of cotton. To this day, the river boats of the United States are far before those of England in every good quality.

The substitution of steamers for sailing packets now took place, and in 1823 attention was turned to the Eastern route. The 'Falcon,' a yacht of scarcely 200 tons, with only auxiliary steam power, made the first voyage to India (Calcutta) early in 1825. The 'Enterprise,' 470 tons, 120 horse-power, followed, and thus steam navigation to India became an established fact.

In 1829, proposals were made to place a line of steamers between London and Alexandria, and between Suez and Bombay; but the Court of Directors of the Honourable East India Company took until March 1832 to give a qualified refusal. In 1834, a select committee was appointed to inquire into the best means of promoting steam communication with India; England was already in communication with Malta and Corfu by means of steam packets, and this was extended to Alexandria in August 1834. In 1835, steam communication with India was effected *viâ* the Isthmus of Suez. In 1837, the Peninsular Company contracted to carry the mails to Gibraltar; and, in 1843, engaged to complete the communication with Calcutta; since which time not a year has passed without some improvement in the route. Attention was by no means exclusively turned to India, for the great importance of steam communication between England and America could not fail to impress itself on the thinking and enterprising minds of that period.

The first steam voyage across the Atlantic was in 1818, by the 'Curaçoa,' 400 tons, 100 horse-power, from Helvoetsluys to Surinam and Curaçoa in thirty-two and a half days, eleven of which were under steam.

In 1832, the 'Royal William,' 1200 tons, 180 horse-power, steamed from Nova Scotia to England in twenty days. In 1835, the Great Western Company was formed; and, in 1838, the 'Great Western,' 1340 tons, 400 horse-power, sailed from Bristol on the 8th of April, and reached New York on the 23rd (fifteen days). The 'Sirius' left Cork on the 4th of April, and arrived at New York on the evening of the 22nd; she was therefore the first steamer to cross the Atlantic direct to New York.

In 1840, the Cunard Line was established, and from that time to the present the number of vessels on the route has been ever increasing; indeed, at the present moment not a day passes without a steamer crossing the Atlantic.

It now only remains to say a few words about the introduction of steam into the Royal Navy. The 'Comet' was the first steamer built for the royal service, under Lord Melville's directions, in 1822. She was built of mahogany at Deptford, by Mr. Oliver Lang, 238 tons, 80 horse-power, has been constantly employed ever since, and only very lately has her name disappeared from the 'Navy List.' At the present day, not a single sailing man-of-war of any magnitude is to be found under the pendant, even three-deckers having been successfully fitted with steam power.

In concluding, it will be necessary to mention very briefly that the earlier steam vessels were fitted with paddles; but that, upon the invention of the screw, in 1837, by Mr. J. Pettit Smith, and by dint of dogged determination on his part, the consideration of its merits was forced on the authorities; and after the expenditure of much patience in overcoming ignorance or prejudice, it was determined to test the screw and the paddle by practical trials between two vessels built on the same lines and with the same horse-power — H.M.S. 'Rattler,' fitted with the screw, and H.M.S. 'Alecto,' fitted with paddles.

In every respect the screw proved its superiority—in light winds and smooth water, in strong gales and heavy head seas, whether under sail or only under steam, the 'Rattler' beat the 'Alecto.' Finally, on the 3rd April, 1845, the two vessels were lashed stern to stern; the 'Alecto' was allowed to get her speed, when the 'Rattler' turned ahead, and in spite of every effort on the part of the 'Alecto,' gave her rival the *coup de grace*, by towing her at least 2½ knots an hour against the full speed of her paddles.

The following facts will give some notion of the relative cost of the screw and the paddle. The original cost of paddle-wheel steamers averaged about 5*l.* per ton greater than that of screws; their current expenses about 8*l.* per ton greater; while the average "measure of cargo" is for screws 0·735 of a ton for each ton, for paddles 0·425 of a ton for each ton.

It is not therefore to be wondered at, that the screw is fast superseding the paddle; indeed, except for river and shallow water service, paddle-wheel steamers are now rarely built. At the same time, it should be mentioned that the action of the screw is not even yet, after thirty years' experience, thoroughly understood, although it is as important for the officer in charge of a steamship to know exactly the influence that the screw has upon the movement of his vessel, as it was for the seaman in the old sailing days to understand the effect which the hauling down a jib and filling a mizen topsail, or hoisting a jib and spilling a mizen topsail, would have in altering the ship's course.

For instance, how few officers either in the Royal Navy or the mercantile marine know a right-handed from a left-handed screw, or the effect of the one or the other upon the steerage of the ship; the study of this effect and the practical application of such knowledge has been left to that admirable body of men, the English pilots, who are justly entitled to be looked upon as the finest portion of the seafaring population of this country. The first question asked by a Gravesend pilot is, "Right or left-handed screw, captain?" and so important does he consider this knowledge to the proper steerage of the ship, that in the event of receiving an unsatisfactory answer, only too often the case, he takes a back turn, in other words goes astern, on the first opportunity to ascertain for himself. It may be useful to mention in reference to this subject, that when a steamer with a right-handed screw is going ahead full speed with the helm amidships, she tends to port, just as if she was answering starboard helm, which must therefore be given with caution. Port helm, on the contrary, must be given freely; the contrary happens when the engines are reversed.

The following table, showing the increase of steam vessels, will give some idea of the growth of this British industry during the last fifty years.

STEAM TONNAGE OF THE UNITED KINGDOM FROM 1820 TO 1874.

Year.	Steamers.	Tons.	Average.
1820	56	8,300	148 tons.
1830	315	33,444	107 „
1840	824	95,807	116 „
1850	1,350	187,631	138 „
1860	2,337	500,144	214 „
1870	3,796	1,202,134	317 „
1874	4,835	1,987,235	411 „

THE PRINCIPLES OF DESIGN AND CONSTRUCTION.

The principles upon which ships are constructed must now be considered.

Although the greatest maritime power in the world, England has rarely produced anything to compare with the designs of continental naval architects. Spain, France, Russia, and Sweden, have all made naval architecture a national object, and every possible encouragement has been given by those nations to the development of the art, as is abundantly proved by the writings of such men as Juan, Bernoulli, Clairbois, Euler, Romme, and Chapman. England on the contrary, while recognizing and occasionally rewarding civil architects for inferior buildings of very doubtful taste, has failed altogether to encourage in the smallest degree an art upon which so much of her prosperity depends.

It is no slight reflection upon us, that, while at the end of the last century, every other branch of useful knowledge had its rudimentary works, little or nothing had been written on naval architecture; we were quite content to borrow from our neighbours, and it must be owned that we were slow even at that.

In those days, the greatest authority on the subject was Sir Walter Raleigh, who wrote about 1600, or nearly two hundred years previously, in his 'Exact Description of the Unconquerable Force of the English Navy,' which he declared was at that time able, "in dispight of any Prince or State in Europe, to command the great and large fields of the ocean." He says further, "In mine own time the shape of our English ships hath been greatly bettered. It is not long since the striking of the top-mast (a wonderful ease to great ships both at sea and in harbour) hath been devised, together with the chain pump, which takes up twice as much water as the ordinary did. We have lately added the bonnet and the drabler to the courses. We have devised studding-sails, topgallant sails, sprit-sails, topsails. The weighing of anchors by the capstone is also new. We have fallen into consideration of the length of cables, and by it we resist the malice of the greatest winds that can blow."

"We have given longer floors to our ships than in elder times, and better bearing under water; whereby they never fall into the sea after the head, and shake the whole body, nor sink stern, nor stoop upon a wind; by which the breaking loose of our ordnance, or the not use of them, with many other discommodities are avoided."

The principles of the art have, it is true, become better known at last by means of certain *private* efforts; for instance, in 1791, a Society was formed for the improvement of naval architecture, and a patriotic bookseller threw open the pages of a periodical which he owned, 'The European Magazine,' for the discussion of this subject, while prizes were offered for the best papers "On the Resistance of Fluids," "On Designs for Vessels," "On the Proportions of Masts," &c.

Later on, a school was attached to the Naval College at Portsmouth, and by these means a great deal of light was thrown on the art of constructing ships; but these efforts died a natural death, giving place to a *quasi* school of Naval Architecture, under the Rev. Dr. Woolley, at South Kensington, and an Institute of Naval Architects, founded in 1860, by Mr. Scott Russell. The latter Society might do good service, if only properly managed; at present the results of its labours have been infinitesimally small, while positive harm has been wrought by the admission to the Institute of unqualified persons, who do little beyond writing M.I.N.A. after their names.

Going back to the fifteenth century, the credit of building the best ships belonged to the Portuguese, the result of the practical experience gained in encountering winds and waves in every variety on those famous voyages of discovery, which gave the Portuguese so proud a pre-eminence in Europe. The Spaniards next carried off the palm, thanks to Columbus, and the lessons learnt by the extension of navigation to the New World.* The Spanish two-decker 'Princesa,' captured by us early in the last century, was the first ship of her day both for good qualities and durability; * she was built of Honduras mahogany.

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* The little squadron of Columbus consisted of three vessels, the 'Santa Maria' or Não, the 'Pinta,' and 'Niña:' the first was less than 100 tons, with a crew of about fifty men; the

In 1637, a three-decked ship of nearly a hundred and fifty guns was launched at Woolwich, called the 'Royal Sovereign,' or the 'Sovereign of the Seas.' She was designed and built by Phineas and Peter Pett; the former was a captain in the Royal Navy, and his ancestors had held the office of Architects of the Royal Navy for two hundred years; his son Peter was the mast builder, and he had made the model of this ship before he was twenty-five years of age. Of this young man it was said: "Pallas herselfe flew into his bosome, and not only injoyned him to the undertaking, but inspired him in the manageing of so exquisite and absolute an architecture."

Heywood says, "Her length by the keel is 128 foote, or thereabout, within some few inches. Her mayne

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second some 50 tons, with only twenty-five men; whilst the 'Niña' measured about 40 tons, with twenty men. The Admiral's ship was the only one with square sails; the other vessels were lateen rigged. The description of the sails of the 'Não' is given by Columbus himself in his journal. He says, "I set all the sails of the ship;—the mainsail with two bonnets, the foresail and spritsail, and the mizen and the main topsail and boat on the poop," meaning no doubt the sail of the boat on the poop.

The squadron left Palos at 8 A.M. on Friday, 3rd August, 1492. The island of San Salvador, now called Watling, was sighted on Friday, 12th October, and a new world discovered.

* "When the old Spanish 70-gun ship 'Princesa,' built of mahogany in 1740, was broken to pieces, so sound and tenacious were her *iron* fastenings that the men were paid double wages for extracting the bolts."—'Dottings on the Roadside in Panama, Nicaragua, and Mosquito,' p. 442.

breadth or widenesse from side to side 48 foote. Her utmost length '*a prora ad puppim*,' 232 foote, and just so many tuns in burden as there have been yeares since our blessed Saviour's incarnation, namely 1637, and not one under or over."

Charnock says of this ship, "The 'Royal Sovereign' was the first great ship that was ever built in England; she was then designed only for splendour and magnificence, and was in some measure the occasion of those loud complaints against ship money in the reign of King Charles I.; but being taken down a deck lower, she became one of the best men-of-war in the world, and so formidable to her enemies, that none of the most daring among them would willingly lie by her side. She had been in almost all the great engagements that had been fought between France and Holland; and in the last fight between the English and French, encountering the 'Wonder of the World,' she so warmly plied the French admiral, that she forced him out of his three-decked wooden castle, and, chasing the 'Royal Sun' before her, forced her to fly for shelter among the rocks, where she became a prey to lesser vessels, that reduced her to ashes. At length, leaky and defective herself with age, she was laid up at Chatham, in order to be rebuilt; but, being set on fire by negligence, she was destroyed 27th January, 1696."

The French, however, have for long completely eclipsed every other nation in the excellence of their ships, in respect to form and good qualities, although not in the materials of which they were built: for instance, the 'Canopus,' a two-decker, captured by the English from them, is acknowledged on all sides to be the finest model of her class afloat, and many of our best ships have been built on her lines.

In 1661, Louis XIV. determined to dispute with England the sovereignty of the seas. He possessed in Colbert one of the wisest of ministers, and the nation, which for centuries had been essentially military, suddenly turned its attention to commerce and the seas.

In that year their marine consisted of four or five small vessels only, but in little more than ten years afterwards the combined fleets of Spain and Holland were bearded by it, and the sovereignty of the Mediterranean disputed. In 1681, the French fleet consisted of 115 line-of-battle ships, and 179 smaller vessels, manned by 39,477 men; and in 1690, a fleet of 84 vessels of war, of which three were of 100 guns and upwards, 10 were of 48 guns, and 22 fire ships, was cruising in British waters!!!

The ambitious designs of Louis XIV. were frustrated and his fleet annihilated, after torrents of blood had been shed; but this striking example should not be forgotten, as it shows how much danger and loss are incurred by overweening confidence in our assumed superiority.

A hundred years later, in 1780, the complaints of naval officers were constant as to the inferiority in speed, stability, and readiness of manœuvring of the English ships as compared with the French; and as a notable instance of these complaints, it may be mentioned that Sir George (afterwards Lord) Rodney wrote to the Secretary of the Admiralty, Mr. Stevens, 31st May, 1780, that as the French fleet "sailed far better than His Majesty's Fleet, they with ease could gain what distance they pleased to windward."

On the other hand, it may be said that England holds her position as the greatest maritime power, rather perhaps by force of numbers than from any excellence in her shipping. She possesses a merchant tonnage (nearly 6,000,000) exceeding that of America, Austria, France, Holland, and Norway combined, and therefore has necessarily a predominant influence in shipping matters; but by empirical tonnage laws she perpetuates the faulty, not to say dangerous, form of vessel which is such a well-known characteristic in English ship building of the present day, whether for home use or foreign demand. Apart from their narrow shape (more like a gaspipe pointed at each end than anything else), such vessels, now commonly constructed with ten times their beam for length, are in fact wanting in all the attributes of a ship, and without steam power would lie like helpless logs on the water.

There are certain well-known principles in designing a ship, any deviation from which inevitably leads to disappointment and disgrace. It is not asserted that these principles are so fixed and immutable as to be incapable of further development; but let the mere theorist ignore them in the smallest degree, and the result is always a failure, and of this we have a notable example before the country at the present time in the 'Bessemer.'

The two leading features in designing a ship, which must never be lost sight of by the naval architect, are displacement and stability. These features are again subdivided into a number of details, and it is upon the practical combination of these details that the excellence of the ship depends.

DISPLACEMENT.

The displacement is the first consideration. This entirely depends upon the service on which it is intended to employ the proposed vessel, and the sea which it is proposed to navigate. With these objects in view, the weights to be carried are calculated; and upon this basis the superstructure can be reared with so much nicety by the practical naval architect, that, upon the launch of the ship, the displacement and the consequent draught of water will be found not to vary from the calculations in any appreciable degree.

It should be here explained, that "displacement" is the amount of water displaced or thrust aside by the immersion of any foreign body in the fluid; and the ruling principle which overrides every other is this, that the water displaced corresponds exactly to the bulk of the body which displaces it. This most important discovery, of the very first rank indeed in relation to the true advancement of the art of ship building, was made by the celebrated Greek mathematician, Archimedes (born B.C. 287). The story, although well known, is worth repeating for the sake of impressing the nature and value of the discovery on the student's mind.

Hieron or Gelon, the reigning prince of Syracuse, had delivered a certain weight of gold to a workman to be made into a votive crown. The latter brought back a crown of the proper weight, which was afterwards suspected to have been alloyed with silver. The king asked Archimedes how he might detect the cheat, the difficulty being to measure the bulk of the crown without melting it into a regular figure; for silver being weight for weight of greater bulk than gold, any alloy of the former in place of an equal weight of the latter would necessarily increase the bulk of the crown. While thinking on this matter, Archimedes went to bathe, and on stepping into the bath, which was full, observed the very simple fact that a quantity of water of the same bulk as his body must flow over before he could immerse himself. It immediately struck him that by immersing a weight of real gold, equal to that which the crown ought to have contained, in a vessel full of water, and observing how much water was left when the weight was taken out again, and afterwards doing the same thing with the crown itself, he could ascertain whether the latter exceeded the former in bulk. In the words of Vitruvius—"As soon as he had hit upon this method of detection he did not wait a moment, but jumped joyfully out of the bath, and running naked towards his own house, called out with a loud voice that he had found what he had sought; for, as he ran, he called out, Εὕρηκα, Εὕρηκα! I have found it, I have found it."

The displacement, or in other words the weight of the ship, having been determined upon, the next consideration is the form or shape which she should take, so as to be best adapted to the service upon which she is to be employed.

In a man-of-war this should soon be determined, for there is no ambiguity as to the duties of an armed vessel carrying the Union Jack: she must be a good sea-boat, able in all weathers to blockade an enemy's port *under sail;* she must be fast, and capable of fighting her guns in a seaway; she must draw little water; she must have steam power on board capable of driving her at a high rate of speed for going into action, or to meet a pressing emergency; her engines and the vital parts of her hull should be protected from shot or shell; and she must be rendered comparatively unsinkable by being divided into numerous watertight compartments by wing-passages, and by athwart ship bulkheads. In other words, she must be a perfect sailing ship, aided by a powerful steam engine.

In respect to a merchant vessel, whether steamer or sailing ship, the essential requisites are different. She should in the first place be a good sea-boat; she should possess the greatest possible capacity for carrying cargo or passengers, or both; she should have good stability; she should be very handy; she should either sail or steam well on the least possible draught of water; and her form and strength should allow her to take the ground without injury to her structure.

These should be the main characteristics of English men-of-war and merchant ships; how far they are to be found in either class of ships at the present day, the accidents and disasters at sea of every day occurrence afford only a too painful means of judging.

STABILITY.

A consideration of the stability of a ship, in other words her power of resisting the effort of the winds and waves to capsize or turn her over, is of the first importance in her construction; it should take precedence of every other consideration, since upon its proper observance depends the safety of crew, passengers, and cargo. The stability of a ship is primarily derived from its form or shape; in other words, from the relation of its length and draught to its beam.

Suppose, for example, a long narrow vessel like a boiler tube pointed at each end (such as the steamers of the present day, with a beam only one-tenth their length); is it possible to discover any element of stability in them? Indeed, unless well immersed, with the centre of gravity as low down as possible, they would capsize from their own inherent want of stability. Place one of these long, narrow ships in a gale, and let the engines break down, when the ship at once falls into the trough or hollow of the sea, rolls gunwales under, and it is a miracle if she escapes foundering. It is more than probable that a very large proportion of the comparatively new vessels lost in such alarming numbers owe their destruction to their want of stability from the faulty design upon which they have been constructed, a species of unseaworthiness to which insufficient thought is given, although a fruitful source of loss of life. No amount of seamanship on board could save such a vessel in the position sketched above; even in a heavy sea with full power of steam the danger is very great; for some portion of the long vessel *must* be out of the water, and as the ship *must* seek her displacement, it follows that as she falls the sea breaks on board, very commonly forward and aft on both sides at the same moment, or amidships, as was the case with the 'London,' with crushing effect; it is only a question of time how long a ship has strength to withstand such hammering and submerging.

Another serious defect in the long and narrow ship is the want of handiness; the sails are useless as any aid to the rudder, which cannot be proportionately increased, and therefore loses much of its effect in a long ship, as may be shown in very few and very simple words. The effect produced by the action of the rudder is inversely as the length of the lever, and as the hull extends in length without proportionate beam, the effect produced is weakened, until in ships of immoderate length its influence is almost lost, and would be lost altogether, if it were not for the artificial aid of the screw acting upon it. This may account in a great measure for the increasing number of collisions; the ship will not answer her helm as quickly as the officer in charge expects, and she collides accordingly. Seamen are not, as a rule, aware of this, but the statistics of collisions tend to prove the correctness of this view. How is it possible otherwise to account for the fact that by far the greater number of collisions occur in clear weather, and in the daytime?

It is a somewhat startling fact that with a considerably larger number of ships, of less tonnage it is true, but still large sailing ships, and not steamers, the collisions of twenty years ago, say 1855, and the amount of tonnage lost, bear no proportion to that of the present day.*

The long narrow ship is the result of an idea that this form of vessel can alone give great carrying capacity, and in the case of steamers insure a high rate of speed with comparatively small steam power; but this is a mistake. Vessels with proper beam can be built cheaper than narrow ones; with carrying capacity undoubtedly as good; the accommodation for passengers better; the expenditure of coal no greater; and possessing, it is believed, undiminished average speed.

Not only are the long, narrow ships, which have become of late years so fearfully prevalent in the United Kingdom, weak in design, dangerous at sea, practically helpless without steam, but they actually cost a larger sum to build than ships of more symmetrical shape, as the following example will show. Take a ship A, 240 by 60, or four beams, the area contents of her upper deck would be 14,400. Take another ship B, 380 by 38, or ten beams, the area contents of her upper deck would be 14,440; both ships may be assumed to be about the same displacement tonnage; but a line drawn round A from port side of stem to stern and back to starboard side of stem would be 560 feet, whereas the circumference of B would give 828 feet—in other words, more than half again as much iron or wood as was required to build A must be used in the construction of B. This is without considering the question of depth or draught, which, it is obvious, is again in favour of A; for B *must* be deep to obtain the requisite stability, which on the contrary A possesses from its natural shape. Moreover, ship A would possess about four times the resistance of B to withstand the strain in a heavy sea or upon a rock or shelving shore—occasions which cause the speedy destruction of so very many long, narrow ships.

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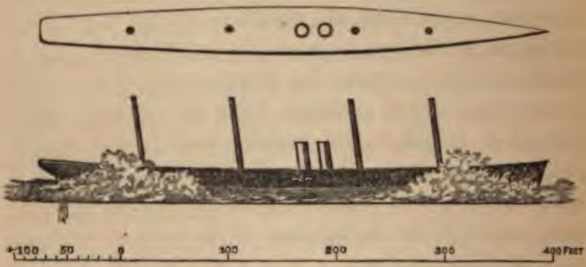
* In 1850 the ships belonging to the British Empire numbered 34,281; tonnage, 4,232,962. The number of ships belonging to the United Kingdom at the same date was 25,131; tonnage, 3,504,944. In 1862 the numbers had reached respectively 39,427 ships, tonnage 6,041,358, for the British Empire, and 27,525, tonnage 4,860,191, for the United Kingdom. It was in this year that the number of ships under the British flag reached their maximum. Last year (1875), the number of ships belonging to the British Empire was about 37,000, with a tonnage of more than 7,500,000. The number of ships belonging to the United Kingdom was a little over 24,800, with a tonnage of nearly 6,000,000, showing that the *size* of our ships has been steadily increasing of late years.

Assuming that B costs 35,000*l.*, A will cost less than 20,000*l.*, be in every respect a better sea-boat, carry more cargo, and, if fitted with deck houses fore and aft, can carry more passengers than B could possibly place between decks; and such a thing as a deck house on board a long, narrow vessel, is obviously out of the question, if safety is thought of for a moment.

The only excuse for perpetuating the fallacy of long, narrow ships, seems to be the supposition, that greater speed at less consumption of fuel can be obtained from such craft, rather than from those of safer proportions. This is certain, that if a ship, say 200 by 25, is cut in half and lengthened 50 feet, she can be driven by a small increase of horse-power and a little more consumption of coal, at nearly the same speed, while she can doubtless carry more cargo; but this does not prove that a long narrow ship is the best adapted for continuous speed in sea-going vessels. The prejudice, however, will probably prevail, until an actual trial of two ships of the same displacement proves that a comparatively short, broad, and light draught vessel, can make a passage on an average quite as quickly as the nondescript craft, now so much the fashion.



Length, 455 feet; beam, 45 feet; depth, 34 feet; tonnage, 3174.

The white circle in the midships of the ship in the diagram indicates the "load line." This outcome of recent legislation is facetiously named by sailors "the mark of the beast;" it is perfectly useless for the purpose intended, that of preventing overloading, and it may be questioned if "the mark of the beast" does not inflict, in foreign ports at least, serious injury on the owner, by sending many a vessel home without freight. The natural inference to the foreign mind is simply that a ship thus stamped is unseaworthy in itself, or that the owner in some way or other is not trustworthy.

Having described the sort of vessel which does *not* combine stability and seaworthiness, it should be mentioned that for centuries the proportion for a vessel approved by builders and sailors alike was about three and a half times the beam for the length; and to this day it may be questioned if these dimensions should be exceeded, most certainly not for men-of-war. Twenty-five years ago, the average of several hundred ships on the Navy List gave a length in proportion to the beam of three and a half. With respect to merchant ships, perhaps some modification may be allowed with safety, although the dimensions given below should never be exceeded, that is, if the question of safety is made the first consideration in designing a ship, as undoubtedly it ought to be. It is believed that attention to this rule would materially diminish the number of wrecks, and consequent fearful loss of life, which is now, to the disgrace of the nation, daily reported in the press; and, moreover, it is further believed that if the form of ships recommended be adopted, such ships would in the long run prove more remunerative to the owner; their original cost would be less; seamen would once more take a pride in their ships, because they were *ships*, and not, as they now call them, "Gaspipes" and "Coffins"; and, finally, as to wear and tear, the superiority of the proposed dimensions is manifest, if only on the one point, that the vessels would go *over* the waves instead of under or through them.

For every 10 feet in length above the proportion of 100 × 25, add 2 feet to the beam, and continue this up to the length of 200 feet, which would give 200 × 45, or a little more than 4½ times the beam for length. For every 10 feet in length above the proportion of 200 × 45, add 1½ foot to the beam, and continue this up to the length of 300 feet, which would give 300 × 60, or exactly 5 times the beam for length. It does not seem desirable to exceed this length, especially in ships designed for making voyages where heavy seas have to be encountered.

Length.	Beam.	Length.	Beam.	Length.	Beam.
100 ×	25	170 ×	39	240 ×	51
110 ×	27	180 ×	41	250 ×	52½
120 ×	29	190 ×	43	260 ×	54
130 ×	31	200 ×	45	270 ×	55½
140 ×	33	210 ×	46½	280 ×	57
150 ×	35	220 ×	48	290 ×	58½
160 ×	37	230 ×	49½	300 ×	60

The space at command precludes the possibility of any lengthened account of that important part of the subject—the rig and sails of vessels. Before the steam-engine was placed on board ship, sails were the sole motive power, and great attention was necessarily paid to their cut and fit. Little by little, improvements and additions were made from the simple large square sail, with the very heavy gear and top-hamper of the ancients, to the fifteen separate sails which a well-found ship sets now-a-days when under all plain sail, or the twenty-one which she spreads to the favouring breeze, when crowding every stitch of canvas.

The progress of improvement in rig and sail making has been very slow indeed; hundreds of years elapsed before a second, and then a third, mast, with appropriate sails, were added to the primitive rig; and several hundred years more passed away before the improvements recorded by Sir Walter Raleigh (page 37), namely, "the bonnet and the drabbler to the courses, studding sails, topgallant sails, sprit-sails, and topsails," were devised. At the present day, although there still remains great room for improvement, there can be no doubt that a ship under full sail, to use the words of Ruskin ('Stones of Venice,' vol. i. p. 209), "is one of the loveliest things man ever made, and one of the noblest; nor do I know any lines out of divine work so lovely as those of the head of a ship, or even as the sweep of the timbers of a small boat—not a race boat, a mere floating chisel, but a broad strong sea-boat, able to breast a wave and break it."

Without in any way impairing the beauty of a ship so lovingly spoken of, it is quite possible to improve her efficiency as a sailing vessel: for instance, by adopting the system of the late Admiral Schomberg, one of the best sailors in the navy, who advocated with great force the desirability of fidding the top masts abaft instead of before the lower masts, one advantage of which would be the rapidity and ease of reducing the top-hamper to the mere lower masts when it was required to steam head to wind, or to take the ship into action.

Not the least necessary part of the naval architect's education should be a thorough mastery of the effect of sails on a ship; this is especially requisite in a maritime country like England, where so much of the carrying trade is done in sailing ships, while in respect to men-of-war it is of the utmost importance. Every possible effort should be made also to perfect the rig and sails of our fighting ships, so as to enable them to keep the seas at all times and seasons independently of steam, which should be looked upon as a latent power, only to be used in battle or in cases of emergency; thus, we should be enabled, as of yore, by at once blockading an enemy, to prevent his inflicting damage on our ports, on those of our colonies, or by means of 'Alabamas' to cut up our commerce.

The table on the next page shows the steady decrease in the percentage of men per 100 tons employed in the mercantile marine, for the most part due to improvements in rig and machinery.

Unfortunately the men-of-war of the present day, especially ironclads, are not only faulty in construction, but have no claim to be considered even good sea-boats; while as sailing vessels, they are worse than useless, and, moreover, as they do not carry more than six, or at most eight, days' fuel, they are utterly unfitted for blockading purposes, where keeping the sea is necessary.

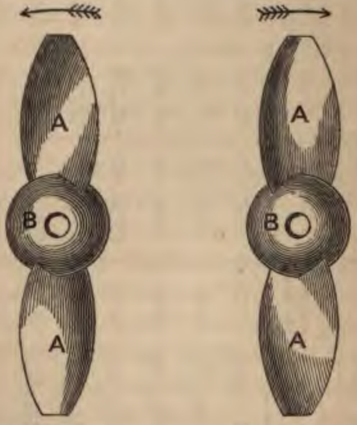
In speaking thus highly of sail power, it is not for one moment intended to depreciate the value of the

NUMBER OF MEN AND BOYS, EXCLUSIVE OF MASTERS, EMPLOYED IN BRITISH SHIPS IN THE TRADE OF THE UNITED KINGDOM.

Years.	SAILING SHIPS.			STEAM VESSELS.			TOTAL.		
	Tons.	Men.	Proportion of men to 100 tons.	Tons.	Men.	Proportion of men to 100 tons.	Tons.	Men.	Proportion of men to 100 tons.
1852	3,215,665	146,286	4·55	165,219	13,277	8·04	3,380,884	159,563	4·72
1854	3,516,456	146,522	4·17	212,637	15,894	7·47	3,729,093	162,416	4·35
1869	4,677,275	152,186	3·25	880,028	43,304	4·92	5,557,303	195,490	3·52
1870	4,519,141	147,207	3·25	1,039,969	48,755	4·69	5,559,110	195,962	3·52
1871	4,343,558	141,035	3·25	1,290,003	58,703	4·55	5,633,561	199,738	3·55
1872	4,245,904	137,101	3·23	1,515,704	66,619	4·40	5,761,608	203,720	3·54
1873	4,067,144	130,877	3·22	1,680,953	71,362	4·24	7,748,907	202,239	3·52
1874	4,037,564	128,733	3·19	1,827,024	74,873	4·10	5,864,588	203,606	3·47

screw; the contention is, that its greatest value is not obtained by employing it exclusively as the main motive power; and this remark, as stated above, has especial force with respect to men-of-war.

A great deal yet remains to be done before screw propulsion will be fully developed; there is as wide a field for improvement here, as in making sail power as effective as it should be. For instance, but few sailors or even engineers thoroughly understand those qualities of the screw, explained at p. 35. The above diagram of a screw propeller will point out its nature at a glance, and show how to judge whether it be right or left-handed. Happily, earnest attention



Left-handed. Right-handed.

Griffiths' Screw Propeller.

is now turned to this important subject, and experiments of a varied nature are being constantly made. Mr. Robert Griffiths, who has interested himself in screw propulsion from the time of the late Sir F. Pettit Smith and Captain Ericsson until now, has lately made some important improvements in his own screw, which is deservedly held in high reputation by professional men. He has proved by experiments carried out on board H.M. gunboat, 'Bruiser,' and the steam pinnace No. 22, that by the simple expedient of encasing the screw, not only is the danger from fouling and wreckage materially decreased, but the vibration, so disagreeable and expensive, is rendered perceptibly less, while at the same time racing, so dangerous to the engines when the screw is out of water, is much diminished.

But perhaps the most important change proposed by Mr. Griffiths is the placing the screw both at the bow and stern in tunnels, by which he calculates that greater speed will be obtained, while a double chance of preserving the motive power from shot, shell, or accident of any sort will be secured; considerable reduction in the diameter of the screws, and consequent decrease in the draught of water will be effected; and finally, that the power of turning, stopping, or going astern much more quickly than at present, will be materially increased.

The question of the adaptation of the screw to marine propulsion must not be dismissed without mentioning an ingenious improvement, introduced by Mr. E. J. Harland, of Belfast, by which the screw shaft is so jointed, that the screw can be lowered or raised at pleasure. The advantage of lowering in a heavy sea, when the wave-line leaves the screw in its ordinary position well out of water, is obvious; while the power of raising the screw above the water-line, either to repair it, or when not required under sail, is equally clear, provided always that the somewhat weak gearing will stand the great wear and tear.

The principle of Mr. Harland's invention has also been applied by Mr. George Angell, of Clerkenwell, to a screw placed within the rudder, which acts with equal facility whether the rudder is amidships or hard over to port or starboard,—and it can be put over 90°! But before this invention can be made practically useful, it is necessary that the jointing should be considerably strengthened, when no doubt for long narrow ships, to turn them in their own length, it would be of great value.

TONNAGE.

This essay, brief and imperfect as it necessarily is, would be still more incomplete, if nothing were said about the question of the measurement of tonnage, which so vitally affects the form and build of our ships.

Whoever is responsible for levying dues upon tonnage calculated by the present system of measurement has inflicted a great injury on the nation, because every effort of the shipbuilder has since been devoted to build ships with the largest capacity on the least register tonnage, regardless of other considerations.

Tonnage is the term used to convey an idea of *the capacity of* vessels, not their weight; but it is a very misleading and inaccurate measure of the real size and displacement of a ship, and the present empirical tonnage law has doubtless led to the adoption of a form or shape manifestly disadvantageous, so far as seaworthy qualities are concerned. The true tonnage of a vessel is simply the number of tons of dead weight which she is capable of carrying in safety,—in other words, her displacement between the light and load water-lines, that is, the difference between her light and load displacements given in tons.

Under the Merchant Shipping Acts, 1854–71, the mode of measurement of the internal cubature is briefly as follows. Measure the length of the ship from the inner plank at the stem to the inner plank at the stern, deducting for rake of stem and stern; divide the length so taken into equal parts, in accordance with the length of the deck. For instance, a deck 50 feet long or under, into four parts; above 50 feet and not exceeding 120 feet, into six parts; above 180 feet and not exceeding 225 feet, into ten equal parts; above 225 feet, into twelve equal parts. Find the sectional area of each part; "number the areas successively 1, 2, 3, &c., No. 1 being at the extreme limit of the length at the bow, and the last number at the extreme limit of the length at the stern; then, whether the length be divided according to the table into four or twelve parts, as in classes 1 and 5, or any intermediate number, as in classes 2, 3, and 4, multiply the second and every even-numbered area by four, and the third and every odd-numbered area (except the first and last) by two; add these products together, and to the sum *add the first* and *last*, if they yield anything; multiply the quantity thus obtained by one-third of the common interval between the areas, and the product will be the cubical contents of the space under the tonnage deck; divide this product by 100, and the quotient being the tonnage under the tonnage deck, shall be deemed to be the register tonnage of the ship," subject to certain additions or deductions for deck-houses, &c., or engine-room space, &c.

Now the first thing observable in the above rule is the unsoundness of taking the *internal* cubature; the next is the arbitrary use of the factor 100, and, thirdly, objection is naturally taken to the deductions allowed to steamers.

As to the first objection, it is manifest that the *external* measurement should be taken, for the weight or displacement is the only true mode of measurement.

With regard to the second, it may fairly be asked why the factor 100 is chosen, when the ascertained contents of a ton of sea-water are 35 cubic feet of 64 lb. each? And with regard to the third, no sound reason whatever can be given for the allowance of space to steamers; indeed, in the earlier years of their history, when it may be supposed that they wanted most encouragement, no such abatement of tonnage was asked for.

This abatement of tonnage to steamers, and empirical method of calculation, is already giving much trouble, which will soon ripen into serious difficulties, especially with the Suez Canal authorities, who very naturally ask for payment on the true and not on the fictitious tonnage of a ship. That this claim is not without reason is shown by a comparison between the registered tonnage and the actual cargo carried by the following steamers, "which have left England with cargoes *twice* the weight of their register tonnage: 'Sandringham,' 738 tons; cargo, 1580 tons. 'Durham Castle,' 1110 tons; cargo, 2226 tons. 'Wellesley,' 737 tons; cargo, 1450 tons. 'H. S. Edwards,' 796 tons; cargo, 1800 tons. 'Mauritania,' 481 tons; cargo, 1180 tons. 'Retriever,' 198 tons; cargo, 401 tons. 'James Groves,' 596 tons; cargo, 1235 tons!"

The magnitude of the evil in respect to the Suez Canal alone is shown by the following table, whereby it will be seen how large a percentage of dues is annually lost to the shareholders:

TONNAGE PASSING THROUGH THE SUEZ CANAL.

Years.	Ships of all Nations.		British Ships.		Approximate proportion per cent. of British to Foreign Tonnage.
	No.	Tonnage.	No.	Tonnage.	
1870	491	436,618	319	291,154	67
1871	761	771,409	496	546,621	71
1872	1081	1,184,890	763	869,584	73
1873	1173	1,409,959	812	1,002,368	71
1874	1264	1,649,188	898	1,209,612	73
1875	1495	2,019,495	1061	1,477,741	73

The subject is so important, that it is thought desirable to append the following simple rule by which not only can the true tonnage be accurately established, but the amount of cargo on board at any moment can be positively ascertained by a reference to the scale of feet, commonly called draught of water, stamped on bow and stern of every ship.

When a vessel has received her full outfit and equipment, with her crew and provisions on board, let the line at which she then floats be marked on the stem and stern post, and the displacement in tons up to this line be ascertained either from the design or by actual measurement of the vessel in dry dock; this will give her light-line tonnage. Then take the horizontal sectional area of the light line, to which add a similar area one foot higher up, divide the product by 2 and again by 35 (which, as stated above, is the number of cubic feet of 64 lb. each in a ton of sea-water), and the result will be the burden or tonnage of the ship when her load-line is 1 foot from her light-line. Repeat this operation foot by foot until the owner says, "Stop! I will not sail my vessel any deeper." The sum of these foot-deep tonnages will be the entire tonnage of the ship, beyond which the owner will load at his peril.

This subdivision of the tonnage into planes of flotation 1 foot in depth will ensure great accuracy, and may be made an immense boon to the shipping interest, as port dues and other shipping charges, instead of as at present, being made payable on the entire registered tonnage of the vessel could be levied with ease by a simple reference to the ship's draught of water, on the weight only of cargo actually on board.

Thus it will be seen how simple and easy is the solution of the tonnage difficulty, if only approached in a right spirit; and it is not too much to say that the sad state of our men-of-war and the disgraceful condition of our merchant service could be met and overcome with equal facility, if only party and personal considerations were put on one side, and the matter grappled with in such a manner, as the vast national interests at stake most surely deserve.

CONCLUSION.

It will of course be understood that mathematical calculations of considerable nicety have to be made in working out the details of displacement, stability, strength of structure, and form; it has, however, been thought better not to cumber this essay with such dry details, but rather to give the student a taste for the subject by writing a general outline, and referring him to the catalogue of works covering the entire subject of Naval Architecture, to be found at the Patent Office, 25, Southampton Buildings, Chancery Lane, London, which contain, so far as is known, every information as to the methods by which a ship, whether of wood or iron, a man-of-war or a merchant ship, a sailing vessel or a steamer, may be designed, built, fitted, and equipped for sea.

But it is not sufficient that the student should acquaint himself with the mere theory of Naval Architecture; he should be a good sailor and practical shipbuilder, thoroughly capable of placing himself mentally in every position in which a ship is likely to find herself during her passage from the cradle to the grave. How many professed naval architects, it may be *asked*, have any experience whatever of the enormous power possessed by waves? Nay, more, is it too much to say that they rarely understand the simple fact, that in order to give a wave a chance to do real damage, the vessel must be nearly as heavy as the water, or the water cannot get a fair blow at it; and that if safety is aimed at, it is most important that the proportions of a ship should be such as to enable it readily to surmount the waves, while its build should throw off the water, instead of enticing it to come on board? If these conditions were better understood by naval architects, it is hard to imagine that any one of the profession could be induced to take the responsibility of designing ships like those of the present day, full (from the sailor's point of view) of inherent defects, and positively dangerous, because narrow, long, and low in the water, so that if a wave meets them amidships, the midship part is responsible for floating both ends, until those ends get a bearing on the water, and *vice versâ*. In both cases the wave breaks on board with overwhelming force. The sea plays about such a ship, as if she were a half-tide rock; but with this difference, that the half-tide rock has a foundation, whereas the long narrow ship has only fathoms of water under her. The real reason why so many classed steamers are lost is not far to seek; and this essay, though necessarily brief, imperfect, and scarcely more than a mere outline of ship building, will not have been written in vain, if attention is turned to a subject not merely of national, but of vital, importance to the Empire.

TELEGRAPHY.

By Robert Sabine, C.E.

The construction of telegraphs ranks amongst the latest of developed manufacturing industries. A century ago telegraphy was only a dream. Lines of a few yards in length were, here and there, being hung up in gardens and rooms, and instruments of the crudest forms were being employed to demonstrate that one day this dream might possibly prove to be a reality. Then, for half a century afterwards, scarcely a year passed without some discovery or invention being made known, which brought the suggestion of a practical telegraph step by step nearer towards realization, till at length we find a telegraph line actually put experimentally upon a few miles of railway. Ten years later the first hesitating attempt was made to cross the Channel. From that date to this—six-and-twenty years—the system of telegraph communication has grown to such gigantic proportions, that every civilized land is now traced by a network of suspended wires, and the bottom of every ocean crossed by submerged cables, placing the most distant points in momentary correspondence. Thus the dream of a century ago has grown into a great public service, into a great science, and into a great manufacturing industry.

It is with telegraphy in its last phase, that is to say, as a manufacturing industry, that we have to do here. But so completely dependent is this industry upon strict scientific principles, that it would be useless to attempt to give an idea of the industry without making clear at the same time the scientific principles upon which it is based.

We do not know what electricity *is*; we only know what it *does*. All that we know of electricity is the phenomena which accompany its manifestation, and for our purpose it is of little importance what its nature may be. The reader's comprehension of the subject may be perhaps rendered easier, supposing him not to be familiar with scientific matters, if he regard electricity in the light of a subtle ether capable of being set in motion; and, when in motion, of being able to perform very powerful effects, when suitable opportunities are given it to spend the energy of its motion in so doing.

We find that the earth is the great reservoir of electricity, from which we draw supplies for all our applications and experiments. We find that all bodies in contact with the earth are in the same electrical state as the earth; but that if separated from it, a portion of their electricity can be taken away from them or more of it can be given to them, and that the deficiency or superabundance so established can only be maintained, on the condition that they are kept electrically separated or *insulated* from the earth. Experiment shows that through some bodies—such as iron, copper, and some liquids—electricity passes freely; and we therefore call them *conductors*. Through other bodies—such as china, indiarubber, and guttapercha—electricity has great difficulty in making its way, and these we therefore call bad conductors or *insulators*. When therefore a conductor is placed upon or supported by an insulator, it is in a condition which is called *insulated*, and its electricity may then be added to or taken away at pleasure, by pumping into it or out of it.

To do this, science has placed at our disposal various apparatus, which, when set in action, exert a pumping effect upon this subtle fluid before and behind them. These apparatus are chiefly known as *frictional machines*, *voltaic batteries*, *thermo-batteries*, and *magneto-electric machines*, and they have all the same purpose, viz. that of transferring electricity from one side to the other; but they differ in the way in which they are set in action, as well as in the quantity and tension of the electricity transferred. By quantity, let us understand something analogous to volume; and by high or low tension, something analogous to high or low pressure as applied to water.

Frictional, magneto-electric, and some other kinds of machines are worked by rotation; the force which is expended and disappears in producing the electricity is provided by hand or other moving power. Voltaic batteries are worked by chemical means alone; the force required to work them being provided by dissolutions and recompositions of their constituent parts. Thermo-batteries are put in action by heat, and therefore heat supplies the force required to set this form of electrical pump at work.

All electrical machines have this property in common, that no electricity is either generated or stored up in them; that is to say, that, when at work, exactly as much electricity comes out at one side as goes in at the other; that if any enter at one side, it is delivered up at the other; and that if none is allowed to enter, none is transferred. To set electricity in motion, energy must be expended; and reciprocally, electricity once freely in motion, can be made to do mechanical work, to produce heat, magnetism, light, or chemical effects. Thus the energy which we impart to electricity in setting it in motion may, at the expense of course of this energy, be returned to us in the same or in a different way. Foremost amongst the effects which electricity in motion can produce is magnetism: it can render two pieces of soft iron mutually attractive, and it can hold deflected a steel needle when magnetized.

The electricity used for telegraphing purposes is, on the great lines of public traffic, almost exclusively voltaic. A long insulated metal wire extends between the people who wish to communicate with each other, the two ends of the wire being put into connection with the earth. The wire, at the end where the message is to be received, is coiled round and round a magnetic needle, which is free to move on an axis passing through its centre. At the home or sending end the operator divides his circuit from time to time and inserts in the break a voltaic battery. The battery then sends a current of electricity flowing through the line, pumping it out of the earth at one end and letting it run back into the earth at the other.

As often as the operator repeats this, which he is enabled to do easily by properly arranged apparatus, he causes the magnetic needle at the other end to turn to the right or to the left, according to the direction in which he inserts his battery, and whether it is put to pump out of the wire or into it; his correspondent at the other end interpreting by some conventional code the intelligence intended to reach him. This method is known as that of the "*single needle.*" Or, instead of winding the wire round and round a suspended magnet needle, it is sometimes coiled closely round a cylinder of soft iron a great many times, by which, whenever a current flows through the line, the soft iron is rendered magnetic and attracts an armature on the end of a rocking beam; and this attraction causing a sharp noise every time it takes place, enables the operator to interpret by ear the signals sent him. This is the *Sounder* system. Or, the other end of the beam carries a blunt pin or a pen of some kind within a short distance of a narrow strip of paper, which a clockwork pulls regularly over it. When the current passes and the armature is attracted to the electro-magnet, the blunt pin or pen at the other end of the beam is elevated and the paper marked by scoring or inking. In either case the number and length of the conventional signs determine their meaning. The first system is that used in England: it is simple, speedy, and little liable to disarrangement of the apparatus; the second is the system common to American lines, and greatly used also by the Post Office in England; the last method is that employed on important commercial lines, when a record is required. Of course there are hundreds of other methods with innumerable refinements and conveniences, but these are the common working ways of telegraphing.

On suspended wires, the rate at which signals can be sent in this way is limited only by the rate at which the operator at one end can put his battery in and out of the circuit at the proper intervals; and that at which the operator at the other end can interpret the signs he receives. The greatest rate attained with manual transmission represents about thirty words per minute; but there exist methods by which the messages may be prepared beforehand, sent by a machine at a very much greater rate, and received at the other end in signals scored in ink, which can be interpreted at leisure. The most successful of these is the "automatic" system, used on all the chief lines in Great Britain and other countries. By this method, holes, corresponding with the signs, are punched out of a long strip of paper, which, when pulled rapidly through a machine, sends the currents flowing through the line at a rate equivalent to about 150 words per minute. With these so-called *automatic* systems, the speed of sending and receiving on suspended wires is limited by the rapidity with which the recurring motions of the machines are capable of taking place with regularity and certainty.

In sending through cables or lines submerged in the sea, however, the rate of signalling is not limited by the movements of the men or the machines, but by a retarding power, which exists to a very small degree in suspended, but to a great degree in submerged lines. It is necessary before proceeding to get an idea of what this retarding power is.

Electricity possesses a distinctive property, to which we know of no analogy. This property is called *induction*, and it amounts in effect to this, that wherever the electric condition of an insulated body is made different from that of the earth, an opposite electrical state is close at hand, on the opposite side of the insulation; and as long as the electric state of the insulated body is kept different from that of the earth, the surplus or deficiency is not distributed over the earth, but hovers as close as it can get to the insulated body.

If we dip a bucketful of water out of the sea, the water closes up and leaves no sign, but we have our bucketful. If we pour a bucketful of water into the sea, it becomes at once common to the great reservoir, and we have an empty bucket. In either case we can show the end of the operation, as far as we are concerned, viz. a full or an empty bucket. But let us imagine such a state of things as this, that if we dipped a bucketful of water, the empty space were to remain when we withdrew the bucket, and if we carried it along the shore, that the empty space would follow us, however far we went; or let us imagine that we emptied a full bucket into the sea, and that the water so poured in, instead of falling into the rest, were to stand up and follow the empty bucket when we carried it away. This sounds absurd, but it is very much like what electricity does, and this is the phenomenon which we call *induction*. It is a behaviour peculiar to electricity, and one which has great influence upon telegraphy. We do not find, when we cool a body, that a corresponding heat follows it wherever we take it; nor, when we light a fire, that a corresponding amount of cold persists in remaining in its neighbourhood until the fire goes out. Reservoirs of both fluids and forces close up as it were so as to hide a surplus or deficiency; but electricity will agree to no such compromise. Once a disturbance of electrical balance takes place, the disturbance lasts, and makes itself conspicuous until equilibrium takes place again. Other matter and other force we may obtain or get rid of, and the deficiency or surplus will be merged in the great mass of terrestrial matter and force; but electricity seems to be endowed with laws of peremptory justice.

It is this mutual attraction between surplus and deficiency in electricity which renders it difficult to work through long submarine lines. Starting a current of electricity means the disturbing of electric equilibrium, and this at once sets induction at work. The fulness of electricity flowing in the cable is accompanied by a corresponding emptiness flowing along outside the cable, or *vice versâ;* or as we say, speaking electrically, the positive electricity flowing in the cable attracts, as it goes along, a negative charge outside it, or *vice versâ*, and this negative outside charge reattracting the internal electricity, holds so much of it back, that it is considerably weakened by the time it reaches the farther end; and, until this retarding attraction is satisfied, the flow of electricity does not attain its full force.

Some appreciable time, therefore, is required, before electricity, pumped into the cable at one end, becomes recognizable at the other; the longer the cable, the longer this interval of time.

Requisite Properties of Telegraph Lines.

In the construction of a line of telegraph the two objects sought to be obtained are: 1, speed of working; and 2, economy of battery power. The speed of working through any line is determined by its inductive capacity and the resistance of its conductor; the economy of battery power is determined by the degree of insulation of the wire. There are therefore three essential requisites for a commercially successful line of telegraph:

1. A low inductive capacity, and } give a high speed
2. A low conductor resistance } of working.
3. A high insulation resistance saves battery power.

In dealing with overhead wires, comparatively little attention is paid to their capacity and resistance, because the induction of the dielectric air, many feet in thickness, which surrounds the wires, being low, they are subject to very little retardation; and as the lengths in single circuit are generally short, a working speed is always possible which is higher than even mechanical manipulation can attain. A high degree of insulation at the points of suspension along the line is, however, desirable, without which large and wasteful batteries become necessary in order to obtain readable signals.

But in dealing with submarine wires, which, from necessary considerations of economy, can only be surrounded with a very spare coating of dielectric material, great care has to be observed, to ensure the best results in regard to induction and conductor resistance, which given quantities of materials can afford. In this case also a high insulation is desirable, not so much with the object of saving the expense of a large battery, as to avoid the injurious effects which the current would exert at the weak places of the cable. For this purpose the engineer employed to superintend the construction of a submarine line has to subject the core length by length, as it is made, to a severe electrical scrutiny, to be sure that the electrical properties which his calculations have led him to anticipate for the quantities which he has specified are fulfilled; and also to insure that the materials supplied possess those electrical conditions which the contractor has promised.

Underground wires are subject to the same causes of retardation as those used in submarine work, but the distances between the stations being short, the working of these lines usually suffers less in practice from induction and conductor resistance than from defective insulation. Buried lines are therefore seldom resorted to, except in large towns, where a great many wires have to be carried in the same direction.

MATERIALS USED IN SUBMARINE CABLES.

Copper Conductor.—The conductor of a submarine cable is usually formed of a strand or rope of seven copper wires, the interstices between them being filled up with a bituminous compound. A conductor of this form is preferable to a solid wire, because it has greater pliability, and may therefore be bent more repeatedly without becoming brittle and breaking.

The copper selected for telegraphic purposes is of as high a conducting power as can be obtained.

The best known conducting bodies are pure silver and pure copper. If there is any difference at all between their conducting powers when they are perfectly pure, silver is believed to be the better conductor of the two, but the difference in any case is so slight, that even if silver could be had for the same price, it would not find any greater employment than copper for the conductors of cables. We may therefore assume that in telegraph cables we have for the wire the best conducting body of which we have any knowledge.

The purer the copper, the higher its conducting power. In telegraph work, the conducting power of pure copper (at 75° Fahr.) is assumed to be equal to 100, and the conducting power of ordinary commercial or impure copper is expressed as so many per cent. of this. Thus, if pure copper be alloyed with 1 per cent. of silver, its conducting power is reduced to 87, that is to say, 87 per cent. of the conducting power of pure copper; if pure copper have mixed with it 1½ per cent. of gold, the conducting power of the resulting alloy is reduced to 66. There is therefore nothing to be gained by seeking to employ other materials than copper for the conductors of cables. All that is necessary is to see that it is as pure as possible, and to use as little of it as will give the requisite speed of working. For this purpose the Lake Superior and Burra-Burra are the best adapted, their conducting powers varying from 89 to 99 per cent. of that of chemically pure copper.

The conducting power of a given metal is not always represented faithfully by the conducting power of a given wire of it. The breaking strain of a fine wire is known to be proportionally much greater than that of a bar of the same material, and it is similar with its conducting power. The reason is in both cases the same; for when a bar is rolled, or a thick wire drawn, it invariably contains faults, sometimes caused by particles of non-metallic matter, and sometimes by bubbles and flaws. When these are measured with it, it is natural that its breaking strain and its conducting power should appear low. But when it is being drawn down to finer gauges, the wire breaks at these places, and the remaining lengths, filtered as it were through the draw-plates, being more homogeneous, have a higher breaking strain, and a higher conducting power also. A strand conductor, therefore, possesses the still further advantages of a somewhat higher tensile strength than would be obtained with a solid wire, independently of its greater pliability.

Insulating Materials.—The materials used for the insulation of submarine lines are: 1, Guttapercha, put on with intermediate coatings of Chatterton's compound; and 2, Indiarubber in a more or less perfectly vulcanized condition. Whichever kind of insulation is used, it is customary to apply the material in several successive coatings, which together make up the thickness necessary for affording the requisite electrical properties, in preference to applying the material in a single coating. The reason for this is, that a fault, which might easily occur in a single coating sufficient to ruin the insulation, is (electrically speaking) reduced to comparative insignificance when covered up in two or three outer coatings, in which it is infinitely improbable that similar faults would occur at identically the same spot.

Guttapercha and Chatterton's Compound.—The native guttapercha is cleansed of impurities and rendered homogeneous by various processes of washing, mastication, and filtration under pressure through fine wire gauze. Guttapercha is applied to the conducting wire by means of a die, through the centre of which it is drawn, and out of which the plastic material (at a temperature of boiling water) is forced under pressure. The conductor, when a strand, is usually coated with Chatterton's compound at the time that it is stranded. When this is the case, the strand, before it passes into the back of the die, traverses a gas jet, which softens the compound, and prevents any irregularities in it affecting the concentricalness of the guttapercha with the wire. The conducting wire, with its first plastic coat of guttapercha, as it leaves the mouth of the die, enters a long trough of cold water, in which it is passed backwards and forwards ten or a dozen times, over and under pulleys, and by this means its coat becomes consolidated. It is believed that in all guttapercha manufactories the core is tested for insulation between the application of each successive coating. Any faults of magnitude are then discovered, and the coating is in those places made good. The core is then covered with a thin layer of Chatterton's compound, which fills up any possible small accidental irregularities in the first coating, and provides a means of cementing the successive coatings together. The following coatings of percha are applied similarly to the first, only, of course, through larger dies; the compound being warmed by passing through a gas-flame, before the unfinished core enters the die.

The same mechanical powers of endurance, which render this material valuable as a substitute for leather for the soles of boots, and for many uses which put its tenacity to severe tests, render it peculiarly adapted for the insulating covering of submarine cables. Gutta-percha is compressible, and, when exposed to the uniform pressure at the bottom of the sea, its insulation improves at the rate of over 50 per cent. for every mile depth in which it is submerged.

Permanence of Guttapercha.—When guttapercha is left in the air uncovered, and especially when exposed to the action of light, it soon becomes brittle and cracks. This may be due to the escape of some essential oil from it, whose presence is necessary to its tenacity; or it may be due to a process of oxidation. But beyond the mere knowledge of the observed facts, and the significant warning which they give, the want of permanence of guttapercha when exposed to light and air is not of importance for the purpose under consideration, as submarine telegraphs are supposed to *exist in quite* different conditions.

In water, guttapercha may be said to be imperishable. In 1851, Mr. Brett laid the Dover-Calais cable, and in 1869, when some of it was recovered, the guttapercha was found to be in a perfectly good condition.

When first manufactured the insulation of guttapercha core is low; but it improves rapidly as it gets older. As an instance of this, a knot length of ordinary guttapercha core manufactured in January was found to have a resistance represented by 188. Its resistance in September had increased to 401, or to more than double its original value, representing an average improvement of 15 per cent. per month.

Indiarubber.—Various methods of applying indiarubber as an insulator to cable cores have been proposed, have been tried, and, in the majority of instances, have failed. Mr. Hooper's process is the only one which has assumed proportions entitling indiarubber to be considered as approaching a level with insulation by guttapercha. Mr. Hooper's cores are covered with vulcanized indiarubber, but they differ from ordinary vulcanized indiarubber cores, inasmuch as the vulcanization is not uniform throughout, but is very slight (in fact, scarcely traceable) in the interior next to the wire, whilst it is comparatively perfect towards the exterior. In this judicious graduation of the vulcanizing consists the peculiarity of what is commonly known as "Hooper's material."

The reason why this graduation is so successful is, that the inductive capacity of indiarubber increases when it is vulcanized, and therefore, the more it is vulcanized, the lower becomes the working speed of a *cable insulated* with it. Hence it would obviously be desirable to insulate cables with pure indiarubber, which might be done were it not for the fact, that pure indiarubber in time becomes treacly, whereas it retains its molecular condition unimpaired when vulcanized to a sufficient degree. Between these two conditions therefore it is necessary to choose a medium course. When the vulcanization is *insufficient*, the core is in danger of becoming tacky; when *sufficiently* vulcanized to prevent this, its electrical virtues are impaired. Mr. Hooper's process has accomplished more than any of the others which have been suggested, to steer clear of both drawbacks. The way in which he prepares his core is as follows:

The copper conductor, tinned on the outside to prevent chemical action setting in between it and the rubber, is covered with two longitudinal strips of *pure* rubber, which form two half tubes about the wire, their freshly-cut edges uniting immediately under the pressure supplied by the circular cutters themselves. A second coating of pure rubber, having its longitudinal joints at right angles to those of the first, is usually applied. These coatings are then enveloped in the same way with one of a material compounded generally of indiarubber and oxide of zinc. Over this is one coating, or sometimes two, of rubber containing sulphur, and, outside all, a spiral lapping of prepared felt, which keeps the whole compact. The coating containing the oxide of zinc is called the *separator*. Its object is to prevent, to a great extent, the sulphur contained in the outer coat vulcanizing the pure rubber in the interior. The vulcanizing process consists in subjecting the whole, whilst laid out on a suitable tray in a superheated steam vessel, to a temperature of 250° Fahr., in which it is baked for some hours. In the baking, it all becomes consolidated into a compact mass; some sulphur penetrates through the "separator," vulcanizing the pure rubber underneath sufficiently to prevent its subsequently becoming tacky, but not so much as to materially lower its high electrical virtues.

Indiarubber-covered wire requires to be more carefully handled than that covered with guttapercha, because the material being very elastic, and fresh wounds in it having the property of being, to some extent, self-healing, it is liable to hide, for a time, faults which are made in it.

As an instance of this, it has been found that if a piece of Hooper's core be sharply struck with a hammer, the material will receive a split, although to outward appearance it remains uninjured; whereas guttapercha, being less elastic, shows its bruises more distinctly, and is therefore less liable to develop faults subsequently, which have had their origin in slight mechanical accidents in the factory.

The Section of the Core.—When a long line of submarine telegraph is determined on, and there is sufficient information as to the condition of the coast on each side, and soundings between them, the route can be decided and the length measured off approximately from the charts. To this length, in subsequent calculations of speed, etc., between 10 and 15 per cent. are added for slack, according to the nature of the bottom. The engineer has then to decide upon the quantities and qualities of materials to be used in the manufacture of the core. These quantities depend upon what is afterwards required of the line, that is to say, how many words per minute it will be necessary, with a certain system, to transmit through it, so as to make it commercially successful.

The data upon which this calculation is based are, the length of the line, and the ratio which it is considered safe to employ between the weights of the insulator and the copper. This ratio between the weights of the materials is simply the weight of insulator divided by the weight of copper; but as it is impossible to say what these weights will have to be, in order to give the required speed, only the ratio which shall exist between them can be determined on at starting.

This ratio varies between 1 and 1·33 for guttapercha, and between 0·8 and 1·2 for Hooper's material. In the Malta-Alexandria (1861) cable, the guttapercha and copper weighed each 400 lb. per knot; the ratio in this cable was therefore $\frac{400}{400} = 1$. In the Atlantic (1866) cable the guttapercha weighed 400 lb. and the copper 300 lb. per knot; the ratio for the cable was therefore $\frac{400}{300} = 1 \cdot 33$. As a rule, the lower this ratio is, the cheaper will be any cable giving the same working speed; because the insulator is much dearer than the conductor, and, within certain limits, a pound of copper added to the conductor does more in increasing the speed, than a pound of insulator added to its covering.

Having determined, therefore, what the

$$\left\{\frac{\text{weight of insulator}}{\text{weight of copper}}\right\}$$

shall be, and calling this ratio (a), the following formula gives the weight of copper in pounds per knot required:

$$w = \frac{s\,l^2}{\text{B log.}\,(1{\cdot}05\sqrt{1+\beta\,a})}\ \text{lb. per knot};$$

s being the required speed in words per minute, l the length of the cable in knots, and β the relation between the specific gravities of the materials of insulator and copper strand.

For guttapercha	$\beta = 6{\cdot}8$
„ Hooper's material	$\beta = 5{\cdot}7$

The numerical constant B varies with the instruments employed and the material of the insulator, and in general cases is as follows:

For guttapercha, with mirror galvanometer	B = 610,000
„ „ Morse apparatus ..	B = 36,500
„ Hooper's material, with mirror galvanometer	B = 810,000
„ „ Morse apparatus ..	B = 49,000

The weight of insulator in lb. per knot is obviously a times w.

In this way are obtained the least weights of insulator and conductor, which, under the given conditions, will afford the required speed of working.

To make this quite clear, let a practical example be taken:

> In a projected cable it is determined to employ equal weights of copper strand and guttapercha (therefore $a = 1$): the length (l) is 2000 knots; and it is required to work with the mirror instrument at the maximum rate (s) of fifteen words a minute.
>
> The weight (w) of copper will therefore be:
>
> $$w = \frac{15 \times 2000^2}{610,000 \times \log. (1 \cdot 05 \sqrt{7 \cdot 8})} = 210 \text{ lb. per knot.}$$

The number of pounds of copper and pounds of insulator of standard quality that will suffice for obtaining the required speed without needless waste of expensive materials can now be specified. The next thing is to ascertain what electrical conditions these quantities represent, that is to say, how much resistance, as a maximum, each knot length of the conductor must have at 75° Fahr.; how much resistance, as a minimum, the dielectric of each knot of the insulated wire should have at the same temperature; and lastly, how much, as a maximum, the electrostatic capacity of each knot length of the core should amount to. To arrive at a knowledge of these figures, an average must be taken of the best cables made upon the different systems; and knowing their dimensions, and knowing also their quantitative electrical conditions, from these can be calculated, by simple rules of proportion, what the quantitative conditions of any intended cable should be.

Uniform Temperature.—In stating the electrical conditions of cable cores, it is the custom to refer to a temperature of 75° Fahr. (24° cent.). During the rigorous system of testing applied in 1860 to the core of the Malta-Alexandria cable, the plan was first adopted of keeping the coils immersed in water, at a temperature of 24° cent., for some hours before they were measured. The reason of this was, that the resistance of guttapercha was found to vary very greatly with slight variations of temperature; an increase of only 10° Fahr. being sufficient to reduce the insulation resistance of this material to half its original value, or a decrease of 10° to increase it about two-fold. Indiarubber is similarly affected, but to a less extent; a difference of about 25° Fahr., one way or the other, being necessary to alter its resistance within the same limits.

It becomes evident, therefore, that in order to arrive at anything approaching an exact knowledge of the electrical conditions of the insulating material, the exact observation of its temperature is the first requisite. And when it is borne in mind that a difference of 1° Fahr. produces a corresponding difference of 6 per cent. in the observed resistance of a guttapercha cable; that an error of 1° Fahr. therefore gives an error of 6 per cent. in the result, it is not surprising that, however carefully the manipulation is carried out, none of the insulation measurements of guttapercha cables, when stored in tanks, are to be depended upon within 10 or 15 per cent.

Notwithstanding that the insulation of these materials alters so greatly with temperature, it has frequently been observed that the full alteration of resistance does not take place simultaneously with the temperature, but some time afterwards, following it with a certain degree of inertia.

Sixteen years ago, during the tests of the Malta-Alexandria cable, it was found that when a coil of guttapercha core (which had acquired a uniform temperature, and whose resistance of copper and dielectric had become constant) was transferred to water of a different temperature, the copper quickly indicated an altered temperature, the guttapercha more slowly; the copper at length indicated to a nicety the exact outer temperature, while the guttapercha was still behind. This phenomenon was also observed in testing the Atlantic cable before submersion. Coils of core, when placed in a tank of water at 24° cent. were found to go on increasing in copper resistance, indicating corresponding changes of temperature always some hours in advance of the guttapercha.

When therefore the temperature of water in which a core or cable is placed is changing, the resistance at any moment does not correspond with the temperature which the core *has*, but that which it *had* some hours before.

In consequence of this fact, the system was introduced, and is still followed, of testing the single lengths of core at the guttapercha factory, after they have been kept immersed in water at 24° cent. for twenty-four hours.

If the coefficients of increment for the conducting power with temperature were exactly known for guttapercha of all thicknesses and of all ages, it would not be necessary to test each coil of a cable at 24° cent., as any other temperature would do as well, provided only that it were not allowed to change during the twenty-four hours immediately preceding the test. But, unfortunately, the tables and coefficients of the resistance of guttapercha for different temperatures are only approximate. There have been elaborate and careful series of determinations made, from which coefficients and tables have been constructed.

These coefficients and tables were, at the time, strictly applicable to the coils which were tested; but since the electrical properties of manufactured core vary with its age, the strict applicability of these coefficients and tables was not to be depended upon a few months afterwards, even for the very coils upon which the experiments were made. And for other coils they are not so, because guttapercha is not always of uniform quality.

The extent to which this material alters may be seen from the following table of resistance of guttapercha core, measured at the freezing point of water, when the resistance at 24° cent. was taken as = 1:

Core.	Resistance at 0° C.
Persian Gulf (1864), core	14·38
French Atlantic (1869)	20·43
Small core (1870)	23·62
Silvertown guttapercha	17·84

For the sake of uniformity, insulation resistance is now measured whenever practicable as 75° Fahr., and when this is impossible, the best known coefficient is used to reduce the result to that temperature. Usually, the insulation resistance is observed after the battery has been applied for one minute, and when speaking of the insulation resistance of any cable without mentioning the time, it is always understood to mean that electrification has been allowed to proceed for one minute before the resistance was observed.

For estimating the electric properties of any projected cable, data of the electric properties and dimensions of the core of similarly insulated cables are taken as standards of merit to obtain numerical constants for certain practical formulæ.

The copper resistance should be

$$\frac{119200}{pw} \text{ ohms per knot at } 24^\circ \text{ C.,}$$

when the quality of the copper specified is such, that its conducting power at that temperature is p per cent. of that of pure copper and the conductor contains w lb. of copper per knot.

The insulation resistance per knot after one minute of a covered strand at 24° C. averages

$$C \log.\left(1{\cdot}05\sqrt{1+\gamma\frac{W}{w}}\right) \text{ megohms.}$$

W = weight of insulator per knot

For guttapercha $C = 769$ and $\gamma = 6{\cdot}8$
For indiarubber $C = 15400$ and $\gamma = 5{\cdot}7$

The electrostatic capacity of a knot of covered strand averages

$$\frac{E}{\log.\left(1{\cdot}05\sqrt{1+\gamma\frac{W}{w}}\right)} \text{ microfarads.}$$

in which

For guttapercha $E = 0 \cdot 1877$ and $\gamma = 6 \cdot 8$
For indiarubber $E = 0 \cdot 1415$ and $\gamma = 5 \cdot 7$

With the aid of these formulæ, it may be predicted what will be, or at least should be, within a small range of the truth, the electrical properties of the particular cable specified, provided the materials used are of the same quality as those taken as standards of merit.

Serving and Sheathing.—So far has been shown how the cable conductor is enclosed in the insulating covering, by the two methods at present employed; and how the electrical properties of the core so constructed can be determined and foretold. These wires, covered up in guttapercha or indiarubber, are, however, too easily liable to mechanical injury to be submerged in the state in which they leave the factory. It becomes necessary, therefore, to encase them in a sheathing which will serve them for an armour against rough usage. To do this effectually, however, their weight must be very considerably increased, and this increased weight entails provision for an increased longitudinal strength.

There are two types of covering for deep sea cables, which have succeeded and have therefore come into extensive use; and between the advantages of these, in the course of a few years, a better judgment may be formed than is possible now.

In type 1, the cable is sheathed with a complete armature of iron wires, the core being first spun round with a serving of jute yarn saturated in tan water. This jute serving is generally applied only as a bed or padding, to prevent the iron wires pressing upon the soft material of the insulator and injuring it; it is however sometimes applied to a greater thickness, in order to allow more iron wires, or wires of a larger guage to be laid round it. The iron wires are then laid round longitudinally close together in a long helix, so as to form a complete iron armour.

In order to prevent the subsequent rusting of these iron wires in the sea, two measures of precaution are taken; 1st, they are galvanized, that is to say, coated with a thin film of zinc; 2nd, the sheathed cable is clothed in a casing of hemp and asphalte, or what is known as Clark's compound.

After the cable is asphalted and before it enters the store-tank, a stream of cold water is allowed to run over it to consolidate the compound. Each layer, as it is coiled into the tank, is covered with a thick coating of whitewash to prevent the layers sticking together.

The second type of successful deep sea cables is that called, in contradistinction, light cable. The core is first spun round with a padding of tanned jute. It is then sheathed with a few iron or steel wires, each of which is embedded independently in the centre of a rope of the best Manilla hemp.

The great difference between these two forms of protection is, that whilst the second type is specifically lighter, it has a much higher proportional breaking strain. Such cables are therefore more easily recoverable, because they bear the weight of a greater length in the sea. They are, however, not so durable as cables belonging to the first type, and will therefore probably be only employed in future where the depths are so great as to preclude the laying or recovery of the other form. In specifying the qualities for the outer covering of any cable, the combination of wires, or of hemp and wires, gives always a greater breaking strain than that which corresponds with the sum of the materials in detail. The breaking strain of a dozen wires forming the sheathing of a cable is greater than a dozen times the average breaking strain of a single wire, and it is perfectly natural that it should be so. When weights are hung upon a wire, the weight that suffices to break it is not its average breaking strain, but the breaking strain of its weakest point. And if a dozen similar wires are combined in the form of a cable, the strongest points of some probably occur just where the weakest points of others are; so that, in breaking them, the strong and weak points have to be broken together. Therefore, the average so obtained is always higher than the average breaking strain of separate wires. The same applies to the hempen strings used in cable coverings. If a series of single hemp strings break at an average weight of 100 lb., a dozen of them twisted together and forming a single rope require considerably more than 1200 lb. to break them.

If the maximum depth of the sea were known in which it was intended to lay any projected cable, the amount of slack had been determined on with which it was to be laid, and the specific gravity of the cable were also known, it would be easy to decide what breaking strain it must have in order to be able to lay it successfully. And if, further, it could be assumed that the bottom of the ocean were hard, the strength necessary for it to have, in order to be recovered, could be calculated with facility. The specific gravity of a cable, however, cannot be known until it has been designed, and therefore it becomes necessary to determine upon the details of the outer covering first, and then, by a backward process, to find if the required conditions of strength will be fulfilled. If they are not, the design is altered—the number of wires or their gauge—until the result appears satisfactory. In this operation actual experience goes much farther than theoretical considerations, and as the cable sometimes sinks deep into the mud at the bottom, from which it must be pulled forth again, and for which no exact calculation is possible, actual experience has justly the best of it.

In any case, the first thing to be observed is to take sufficient wires to cover the cable well, including a sufficient serving or padding to protect the core. As a rule, however, it is well to bear in mind that the fewer the wires and the larger their gauge, the less surface is presented for rusting. There are two ways in which the weight of hemp serving or padding may be approximately calculated. In the first place, it may be found when the diameter (d) in inches of one of the (n) separate wires which cover the cable, the diameter (D_1) of the finished cable, and the diameter (D) of the core are known, by the following formula,

$$23\left(D_1^2 - D^2 - n\,d^2\right) \text{ cwt.}$$

which gives the weight of the hemp in cwt. per knot.

The other way to do this is to make a drawing to scale of the transverse section of the cable. The diameter of the common centre-line of the outer wires is then divided into two parts (a and b) by the exterior of the core on one side. If the diameter of a single wire be (d) inches and there be (n) of them, the weight of the hemp serving, per knot, is given by the following formula,

$$92\left(a\,b - \frac{n\,d^2}{8}\right) \text{ cwt.}$$

If the cable is to be laid in this form without any bituminous casing, its specific gravity can be calculated and its weight in sea water ascertained approximately. To obtain the true specific gravity of a cable, it would be first of all necessary to exclude all air from the fibres of the hemp. When a piece of finished cable is thrown into water, however, the air is not entirely excluded, and tends to buoy it up slightly. Much of the air contained in the fibres is probably never entirely excluded.

Cable Laying.—The finished telegraph cable, coiled carefully in water-tight tanks on board a suitable steamer, is sent out to its intended destination in as perfect an electrical and mechanical condition as the engineer can obtain. The real troubles of the submarine telegraph only begin with the paying out. At the factory a fault is of minor importance; but at sea, and especially during the process of submersion, the discovery of a faulty place is attended with very serious trouble. Proportional care is therefore taken to avoid contingencies of this nature. The process of paying out cables is simple enough in principle. In the early days of cable laying, engineers were employed to superintend the operation; more recently it has been found that the chief work is in handling the ship, and that therefore more limited intelligence suffices.

The cable near the shore is always heavily covered with iron wires to protect it against anchorage and the action of tides and waves. Farther out to sea, where the depths are greater, one of the lighter types of cable is taken. The cable as it leaves the tank on board the ship, is passed over a series of pulleys, and over a break apparatus, which prevents it running out too fast, and over the stern of the ship into the sea. A certain percentage of slack (10 to 15) is allowed for irregularities of the bottom. When a fault is found to have occurred in a submerged line, it has to be grappled for and fished up again at the faulty place and repaired. Sometimes this operation is an expensive one; the reparation of a single fault costing 20,000*l.* to 50,000*l.* in such cables as those which join America and Ireland.

Since the late Sir C. Wheatstone, in 1840, prepared plans for a submarine cable between France and England, a scheme which was actually carried out only ten years afterwards by Mr. Brett, something like 55,000 miles of cable have been submerged at a total cost of little under 15,000,000*l.*; of all this little more than half is at present in workable condition. The lifetime of a deep-sea cable would not appear to extend on an average beyond ten years; therefore in the administration of such a line, provision should be made out of profits for a renewal at least once within that period. The lifetimes of past and present cables have been rather chequered: with some, comparatively few repairs have been required; with others, the broken down state would seem to be their normal condition. Unless proper provision is made to meet the expense of repeated repairs, to have duplicate cables, so that one can always carry messages when the other is being repaired, and to effect entire renewals at no distant periods, no deep-sea cable company can avoid being in the end a financial failure. The result of a desire to cheapen unreasonably the tariffs for long submarine lines, must be to prevent proper provision being made for these requirements, and then the invested capital of the company must be continually increased without a proportional increase in the value of their property.

With the amount of money which has been expended in establishing submarine cables, much more might have been effected, had the interests of the telegraphing public and of the shareholders been as faithfully considered in all cases as the interests of the contractors and the financiers.

OVERHEAD TELEGRAPH LINES.

The construction of overhead telegraph lines demands very little engineering skill; consisting mainly in hanging up and stretching given lengths of good iron wire in such a way that the loss of electricity at the points of suspension is as little as possible, that they are not so tight as to break through contraction in cold weather, nor so slack as to be blown into contact with each other, or with anything else, in high winds. The insulation of the points of suspension is effected by hanging the wires upon, or tying them to what are called *insulators*, that is, suitably formed cups of porcelain or stoneware which are screwed to the supports or held by brackets.

Overhead lines may be subdivided into overland lines and overhouse lines. For supporting overland lines, it is customary in England to employ wooden poles. These are planted a few feet in the earth to keep them firm, and stand 20 feet or so out of the earth, their thickness depending of course upon the number of wires which they are intended to carry.

Wooden Posts.—Mr. Culley * says that he finds good foreign timber to be the most durable; but that it is too dear to be used in England, unless in positions where appearance and great strength are an object. A very serviceable wood is English larch of thirty to forty years' growth, cut close to the ground so as to obtain the "natural butt" of the tree. By preference the poles are prepared, before being used, by treatment with some antiseptic, such as creosote or sulphate of copper, which adds greatly to their durability. When, however, seasoned poles are used unprepared, it is recommended that the butt ends should be well roasted over a slow fire, and slightly charred from the end to about a foot above the intended ground line. It should then be tarred, whilst hot, with a mixture of four parts of gas tar (boiled with powdered quicklime to expel water and ammonia) and one part of Stockholm tar. It is recommended that, after being planted on the line, the poles should be allowed to remain three or four months before being painted, in order to enable them to dry thoroughly. The painting should be done only in very dry weather. When unseasoned timber is employed, the butts are charred and baked, but not tarred, because the tar prevents green timber drying, and thus facilitates decay. The tarring then takes place, after the poles have been planted sufficiently long to enable them to get thoroughly dry.

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* 'Handbook of Practical Telegraphy,' sixth ed., p. 126.

On the Post Office system, for lines of ten wires or less, a diameter of 5 inches at the top is considered sufficient; if more than ten wires, 6 inches. About twenty such poles are employed, per mile, on straight portions of the lines and more at curved portions.

The whole cost of telegraph poles of about 25 feet in length may be roughly estimated as follows:

Scotch fir	per lineal foot	2*d.* to 3*d.*
" sulphate of copper	"	4*d.* " 5*d.*
Baltic red pine ..	"	4½*d.* " 5*d.*
" creosoted ..	"	6*d.* " 6½*d.*

Iron telegraph poles are greatly used in South America and Australia, the best being those of Siemens, Oppenheimer, and Hamilton. Siemens' poles are made with a cast iron socket, having a Mallet's buckled plate for a foot, and carrying a welded conical tube above. Oppenheimer's poles are made telescopic, and are more easily packed. Hamilton's poles are made of sheet iron bent into a circular section and riveted. Iron poles are much more durable than wooden, and hence their great value for countries where repairs and renewals are attended with difficulty. The cost of iron is however much greater than of wood. The cost of any form of iron pole may be roughly estimated at 1*s.* 6*d.* to 2*s.* per foot run.

Wires.—For long and important lines, No. 4 galvanized iron wire is used; for ordinary lines, No. 8; and for short lines No. 11, B.W.G. Great attention is paid to the manufacture of telegraph wire. The best quality is drawn in lengths of 80 to 120 lb. without welds, and it is "killed" or stretched about 2 per cent. in the manufacture, by passing it over two drums, of which one has a rather larger diameter than the other. It is also made to pass under considerable strain over and under a series of pulleys or studs placed zig-zag, so as to open and break any splits or faults which may exist in it.

The tests to which telegraph wire is subjected are, a breaking strain and the number of times that a length of 6 inches of the wire can be twisted round its own axis without breaking. The breaking strain may be roughly estimated as follows for good telegraph wire:

No. 4 B.W.G. breaking strain = 3000 lb.
" 8 " " = 1500
" 11 " " = 900

All telegraph wire should be galvanized, i. e. coated with zinc.

Insulators.—The insulator mostly used in England is known as Varley's; it consists of two inverted cups of earthenware, one cemented inside the other, and supported by a central pin cemented in the interior, and held by a bracket which is screwed to the pole. The cost of these insulators with brackets complete may be estimated approximately as follows:

	s.	*d.*
For No. 4 wire	2	0 each.
" 8 "	1	6
" 11 "	1	1

On the Continent the insulators most commonly used are made of white porcelain and are somewhat dearer. Siemens' insulator is a very good one, but dear. It consists of a cast-iron hood protecting an inverted porcelain cup, inside which is cemented a hook to which the wire is suspended.

Earth Plates.—Half the telegraph circuit consists of the Earth. Therefore a good contact between it and the wire is indispensable, in order to pump the electricity either out of or into it. At the ends of lines of great importance, the earth plates should consist of sheets of copper at the ends of insulated copper wires, buried at a sufficient depth to insure their being continually wet, or submerged in a river or other piece of water. Water pipes form very good earths, and gas pipes also; but the latter are less to be recommended from their liability to leak, and the gas to become ignited in case of a stroke of lightning.

Resistance of Overhead Wires.—The wire resistance of overhead lines depends upon the quality of the iron, the size of the wire, and temperature: approximately the conducting resistances of average wires are as follows at mean temperatures:

No. 4 B.W.G.	7·7	ohms per	statute mile.
„ 8 „	16·5	„	„
„ 11 „	30·0	„	„

This resistance increases at the rate of 0·2 per cent. for each degree Fahrenheit of temperature.

The *insulation resistance* of overhead wire varies with the condition of the weather. When the weather is fine and dry along the whole line, the insulation resistance will sometimes rise as high as 100 megohms per mile. When the weather is rainy along the whole length of the line the insulation resistance will frequently fall to one-tenth of a megohm per mile. Sometimes the weather is fine at some parts and rainy at other parts of a long line; in this case a medium value is generally found.

Induction of overhead wires is observed to a much less extent than in submarine cables or in buried wires. The electro-static capacity of overhead lines averages 1 microfarad per 100 miles of wire. It is not easily measured, on account of the usually low insulation, and the wire resistance, which combine to facilitate the escape of the charge over the insulators, before it has time to return to the measuring instrument. In general, the consideration of induction on overhead lines is entirely neglected; but in dealing with duplex systems which have lately come into use, it becomes necessary to take its effect numerically into account.

Sag of Wire.—It is impossible to strain a wire between two supports in such a way as to form a straight line. The dip or sag, that is, the vertical distance between the wire and a straight line joining the supports is less, the tighter the wire is strained. The wire should never be drawn up so tightly that its maximum strain is more than one-sixth of the estimated breaking strain of the wire.

The following table will enable the strain to be calculated for any wire, when the span and sag are known.

Relation of Span to sag.	(k) Number Proportional to Strain.
100 to 1	42
120 „ 1	51
140 „ 1	59
160 „ 1	68
180 „ 1	76
200 „ 1	85
250 „ 1	106
300 „ 1	127
350 „ 1	148
400 „ 1	169

To find the actual strain in pounds, multiply the sectional area of the wire in square inches by the span in feet, and the product by the value (k) given in the table opposite to the nearest relation of the span to the sag.

Stays and Struts.—When the line makes an angle at a pole, the pole requires to be stayed or strutted. When the strains of the opposite sides are equal, the strut or stay should bisect the angle which the wire makes at the pole. But as it more generally happens that the two spans have different strains, the strut or stay has to be placed accordingly. To find the best direction under such circumstances in which to place the strut or stay, the simplest rule is as follows: Find by the foregoing table or otherwise the values of the two strains; measure off from the pole in the direction of each wire a length *proportional* to its strain. Join the ends of the measured lengths by a straight line, the middle point of which sighted towards the post gives the proper line for strut or stay.

At curves it is customary to let the poles lean back slightly against the strain. Stays of iron wire are much cheaper than struts; but the latter are steadier and more durable. At points of great strain it is not unfrequent to see two poles trussed together like a girder, in such a way that one forms a strut to the other.

Earth wires are used with doubtful advantage to connect the iron brackets of insulators to earth. They consist of lengths of iron wire twisted or screwed under the bracket, stapled down the post and buried in the earth. The object in view is to carry off any leakage through a faulty insulator and prevent it getting into and disturbing the other line wires. As a rule, these earth wires make a very bad earth connection, and may serve to increase the danger which they are designed to prevent. It is better to dispense with them altogether.

Disturbances in Overhead Wires.—Earth currents and currents induced by the passage of charged clouds, cause frequent disturbances in the working of overhead wires, and discharges of lightning not unfrequently injure and even destroy the instruments. It would appear, from the behaviour of telegraph cables, that there exist also currents of electricity in the earth itself. The currents induced or produced by these are called "earth currents." They occur most frequently during the aurora borealis, and in wires lying south-east and north-west. The hour of the day appears to affect the direction and strength of these earth currents. These currents, which are probably always passing to a greater or less extent, are not always sufficiently strong to cause inconvenience or even to be observed. At their maximum they have a tension of under 100 Daniell's elements.

The action of atmospheric electricity is found very troublesome in working telegraph lines. When a charged cloud passes over a wire, it induces in it an increasing opposite charge, which is released when the cloud passes off, and flows as a current through the instruments at the stations. If, however, instead of the cloud passing off, it should meet another cloud and a flash of lightning take place between them, the cloud becoming suddenly neutralized the charge in the line wire is set free, and passes as suddenly and with a more or less damaging effect through the instruments at the station.

Actual lightning stroke is seldom met with, as the insulators carry it off. But such instances are on record. In order to avoid danger to apparatus from the discharge of atmospheric electricity, apparatus called lightning guards are employed, and during storms, as a rule, instruments are either short-circuited or removed.

Lightning Guards.—A very excellent form is that in which two flat surfaces are kept near together: one in connection with the line, and one in connection with earth. The distance between the plates is so small, that any electricity from the atmosphere reaching the line will spring over to the earth plate rather than traverse the coils of the apparatus, and go that way to earth. These plates are sometimes ribbed in opposite directions, so as to make their opposite faces equivalent to a great number of points. When this is the case, this form of lightning guard loses a chief virtue, which is that of acting as an induction surface which may change the tension of the electricity as it passes, and render it comparatively harmless.

An inferior form of discharger is made, by opposing plates furnished with a great many pin points, so as to facilitate the electrical discharge. In this form, the pins are sometimes fused together by the action of the discharge.

Probably the best form is that made by a combination of the two systems.

Another method consists in twisting two wires insulated with silk round each other, one connecting the line and the other the earth to the apparatus. A discharge fuses the wires together.

S. A. Varley's lightning discharger is the cheapest and perhaps as efficient as any. A metallic tube, in connection with earth, contains a powder of carbon semiconducting, while a screw point from each line is placed in close proximity with a screw point from earth. When the powder is rammed in simply, it has a very great resistance for ordinary currents, so much so as to prevent any loss of current over the points being observable. But this powder possesses the peculiar property, that as soon as a discharge of high tension electricity passes through it, a bridge of particles is formed between the screw points, which is highly conducting and effectually short-circuits the apparatus. When the storm is over, this conducting bridge may be broken, and the guard restored to its usual condition, by simply tapping it with the finger.

European Telegraphs.—The extent of the system of lines belonging to the principal European governments was, in 1872, as follows:

	Miles of Wire.	Miles of Line.
Great Britain	99,918	23,878
France	79,690	29,481
Russia	68,858	34,914
Germany	60,816	17,661
Italy	41,543	12,087
Austria	31,510	11,995
Hungary	26,334	7,781
Spain	16,572	7,287
Bavaria	13,875	4,256
Sweden	11,196	4,371
Belgium	10,947	2,853
Switzerland	7,837	3,429
Holland	6,992	2,039
Norway	6,274	4,012
Denmark	3,988	1,529
Portugal	3,550	1,929
Wurtemburg	3,000	1,378

We may see from this that, independently of railway and private lines, the government systems of Europe comprise 500,000 miles of telegraph wire. The greatest length of wire is possessed by the English Post Office, which is equal to all the lines in Germany and Austria together. Next to Great Britain, France has made the greatest progress; then Russia.

PRIVATE WIRES.

In the year 1870, the Universal Private Telegraph Co., which had been formed for letting out on hire lines of telegraphs and instruments to private firms and others, was bought up by the Post Office. The Company possessed at the time nearly 4000 miles of wire and 2000 instruments. Since that date, the Post Office has carried on the business with striking success and with very little opposition, notwithstanding that this branch of the telegraph business is perfectly open to competition. The extension of the private lines by the Post Office since 1870 is tabulated below: the data being extracted from the Postmaster General's Reports.

Years ending March 31.	Contracts.	Miles of Wire.		Instruments.		Rentals.	
		Total.	Average per Contract.	Total.	Per Contract.	Total.	Average per Renter.
						£	£
1870	775	3,971	5·12	1,901	2·45	26,426	34
1871	824	4,052	4·92	2,026	2·46	28,032	34
1872	914	4,345	4·75	2,19	2·41	31,608	35
1873	1,092	4,194	4·76	2,717	2·49	33,436	35
1874	1,339	5,926	4·43	3,303	2·47	47,007	35
1875	1,493	5,487	3·69	3,785	2·54	52,708	35

The average length of private wires is probably under 3 miles, but the above table shows the average length of wire per contract at a higher figure; this is due chiefly to the fact that between 1870 and 1874, over 1000 miles of wire and over 100 instruments which had been maintained by certain companies ceased to be classed as private wires of the Post Office system. A good deal of private wire also must be in disuse, which to a great extent is due to the faulty condition of the suspended cables, which were put up some years ago. The average number of instruments per contract shows that the Post Office possesses a reserve of about 27 per cent. for exchanges during repairs; but this includes also old sets acquired from the companies.

The price charged by the Post Office for the rental of private wires is 8*l.* per statute mile, and for the instruments 6*l.* per station per annum, including maintenance. In some instances, private wires are the property of the firms using them; in others they are let out at a rental by contractors. Sometimes the wires are the property of private firms, and the instruments hired from contractors. Of all kinds, including the lines let out by the Post Office and by firms or telegraph contractors, and the lines owned privately, the total length of suspended wire in the United Kingdom employed for purposes of private telegrams alone is scarcely under 10,000 miles.

Overhouse wires are for the most part attached to chimney stacks or the corners of buildings, roofs, church steeples, or whatever offers a convenient support and for the use of which permission can be obtained from the tenant or proprietor, on reasonable terms. The terms demanded by owners of roofs, &c. for this accommodation are very various; very few are found to be exorbitant, the majority demanding only a nominal rental, and an undertaking that the line shall be removed on a short notice and all damages repaired. The importance and great convenience of telegraphs is becoming so generally recognized that comparatively few instances of unintelligent greediness or obstructiveness are met with.

The wire most commonly employed is a light strand of three No. 18. B.W.G. galvanized iron wire of thoroughly good quality. Stranded wire is not so liable as a solid wire to be set in noisy vibration by the wind.

The supports which are found most convenient are the double or single shackle insulators. The way in which they are affixed to chimney stacks, &c., is various, being sometimes held by a bolt, sometimes by a length of wire tied round the chimney stack. In passing over streets an endeavour is made to cross at right angles, if the requisite permissions can be obtained. The cost price of erecting overhouse wires without poles may be roughly estimated at 1*d.* per yard for materials, and 1*d.* per yard for labour.

Posts when used are generally of iron planted in a cast-iron saddle or foot on the ridge of the roof and stayed with three or four good wire stays to the parapet walls, the sides of the house, or the feet of chimney stacks.

Formerly several insulated wires were made up into a cable, and suspended by hooks from a pair of wires stretched side by side. These cables were required to be very light, and hence the difficulty of ensuring a sufficient degree of insulation to enable the circuits to be worked without interfering with each other.

INSTRUMENTS.

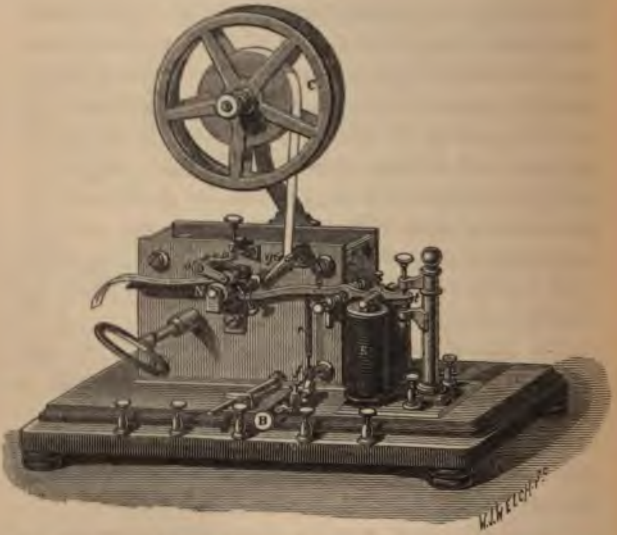
Thomson's Mirror Instrument.—The most delicate and perhaps the most valuable of all telegraphic instruments is the very simple and beautiful mirror galvanometer of Professor W. Thomson, of Glasgow. It consists of a galvanometer, having a magnet needle suspended by a silk fibre, and attached to the needle a small mirror which reflects a beam of light from a lamp, on to a paper scale. It is obvious that the beam weighs nothing, and therefore that the slightest movement of the magnet may be multiplied immensely without costing any force to effect the multiplication. In this way and with this instrument the Atlantic cables were rendered commercially available, which would, with other instruments, have worked much too slowly to be profitable.

The Morse system is the most generally in use, being employed on all the ordinary lines of traffic in the kingdom and on the Continent. Of these instruments the Post Office has in work about 1800, the total number in use on European government lines being over 20,000.

This instrument consists of an electro-magnet, the armature of which is carried by a lever, which carries also a pen or pencil for scoring lines on a strip of paper drawn over it regularly by clockwork, according to the length of time during which the armature is attracted. The signals are transmitted by the operator by means of a suitable key, with the assistance of which he inserts at proper intervals a galvanic battery in the circuit.

The form of Morse receiver most commonly employed on the French lines of telegraph is shown in Fig. 1. The part set in motion by the clockwork is

FIG. 1.



the roller (N), by which the paper strip is drawn from a reel (C) placed above the instrument through the slit (*g*) under the guide-pulley (*b*) and in front of the scoring pen (*i*). A jockey roller, turning loosely on its axis, is pressed down on the paper by the force of a spring (*m*), and thus keeps the paper firmly pressed upon the roller (N), which draws it forwards.

The part set in motion by the electric current is the armature (A), held on the end of a beam, turning on the axle (*v v′*). The armature is attracted to the poles of the electro-magnet (E), when a current of sufficient strength is sent through the wire coil. On being thus deflected, the lever causes the scoring point to be forced against the paper strip, and held against it as long as the current lasts. An instantaneous or very short current gives a dot only, a current of longer duration gives a dash. In other forms of this apparatus, instead of the scoring point shown in the figure, an inking disc is employed, the signals being then recorded in ink. Of combinations of these dots and dashes the so-called Morse alphabet is composed. It is as follows:

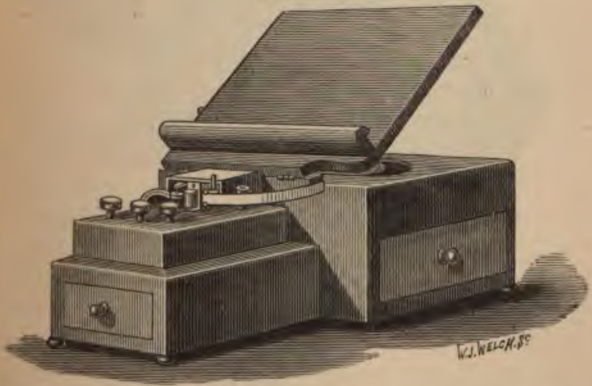
A - —
B — - - -
C — - — -
D — - -
E -
F - - — -
G — — -
H - - - -
I - -
J - — — —
K — - —
L - — - -
M — —
N — -
O — — —
P - — — -
Q — — - —
R - — -
S - - -
T —
U - - —
V - - - —
W - — —
X — - - —
Y — - — —
Z — — - -
Ch — — — —

The Morse Relay.—When long distances have to be worked through, it is common to employ a relay and local battery. The relays are of two kinds, viz. simple electro-magnetic and polarized. The simple relay consists of an electro-magnet, the coils of which are in the line circuit, and of its armature, held upon a short lever, which when deflected comes into contact with a suitable stud or anvil, and thus closes the local circuit which contains a battery and the coils of the Morse apparatus. When no current passes, the lever is drawn back by a spiral spring.

The polarized relay is more complicated, the armature being polarized or magnetized by the proximity of a permanent steel magnet. In the form commonly used in the Post Office, the relay armature or tongue is suspended between the two poles of the electro-magnet, both of which are similarly magnetized and opposite in polarity to the tongue, which will therefore remain at rest against either side towards which it may be deflected. When a current is sent through the coils it weakens the magnetism of one pole and strengthens that of the other, so that the armature is either moved to the opposite side or remains steady in its place. When a line is worked with alternately positive and negative currents, the relay is adjusted so that the effect of each pole is equal; but when worked with a single current, one pole is approached nearer to the armature, so as to bring it back by its magnetism immediately after the cessation of the current.

Fast Speed, or Automatic System.—The first in importance in regard of speed, and therefore in the amount of work which it gets through in a given time, is the fast speed or automatic system of Sir Charles Wheatstone. The Post Office employs it upon all the most important trunk lines in the United Kingdom. With these automatic instruments a speed of one hundred and twenty words a minute is easily kept up; and during a single night, when important ministerial statements are made in Parliament, upwards of two hundred thousand words, or matter which is equivalent to one hundred columns of the 'Times' newspaper, are frequently transmitted from the central station in London by the aid of these instruments, for publication in provincial newspapers.

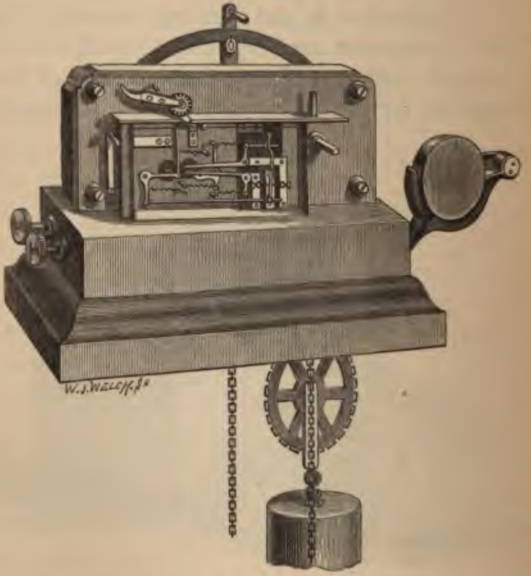
FIG. 2.



In the automatic system, the transmission of the signals is not done by the hand of the operator, but by means of a perforated ribbon of paper which is prepared beforehand, and effects through suitable mechanism the required contacts. The perforations are made by an instrument called the *puncher* (see Fig. 2), which is provided with three finger keys; one punches the holes required to send a dot, another those for a dash, whilst the third punches the spaces.

The Transmitter is shown in Fig. 3. In the front of the instrument is an ebonite rocking beam moved by clockwork. The beam carries three arms or pins. The left-hand arm is connected to line, the arm

FIG. 3.



to the extreme right to earth, while the centre one is insulated. This insulated arm makes contact with one of the battery poles, according to the position of the rocker. Beneath the rocker are two levers connected electrically together by means of springs, and carrying each a vertical needle. These needles, which determine the nature of the current sent to line, are directed by means of the perforated paper ribbon, through which, if there should be a hole, one of them passes, and the arms on the rocker making contact with one or other of the levers, a current is sent to line; but should the surface of the paper be entire, the needle cannot rise, its lever is kept depressed, the contact is broken with the line-pin on the rocker, and no current passes to line. By this system of contacts a far safer transmission can be attained than would be possible were the paper passed between two metallic surfaces simply making contact between themselves, as was done in the original Bain system; and there is the further advantage that all contact-points are under glass, protected from dust and oxidation.

The *Recorder*, or *Printer*, is shown in Fig. 4. It consists of a clockwork and electro-magnetic arrangement similar in principle to that of the "Morse," shown in Fig. 1, only more delicate and quicker in its action. The paper ribbon is carried on a reel in a horizontal drawer in the base of the instrument, and is drawn by the clockwork over suitable guide-rollers close to a small rotating disc which is carried on the end of an arm attached to the tongue of an electro-magnet. This disc is fed with ink from a reservoir, and as it follows the motions of the tongue of the electro-magnet, it traces upon the paper marks which correspond in order and succession with the signalling currents sent into the line by the transmitter at the other end.

A lever moving over a graduated arc at the back of the instrument enables the operator to adjust the speed with which the paper is drawn through so as to suit the rate of transmission.

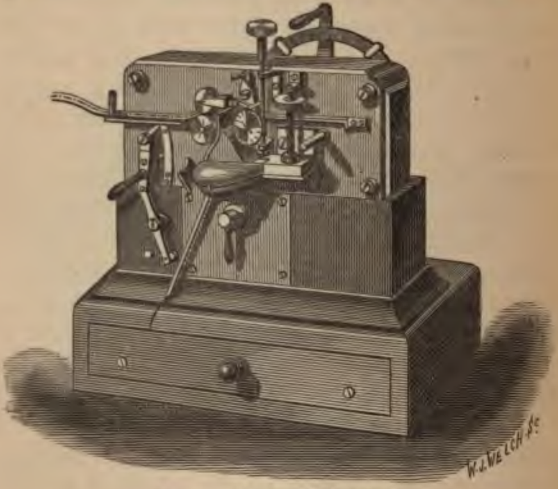


FIG. 4.—Automatic Receiver.

These instruments are generally arranged so as to work either in single circuit or "*duplex*." By duplex working is meant that two messages are sent at the *same time* on the same line wire in opposite directions.

The Sounder is an American invention, which was first suggested by the clerks reading the Morse by sound, and disregarding the paper strip.

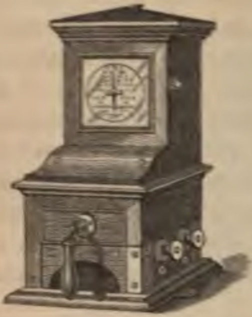
The speed with which messages can be read by sound is greater than by sight, and is less fatiguing to the operators. Beyond this it is asserted that, although the sounder is a system which leaves no record for the justification of the department and of the operators, fewer mistakes arise than with the Morse system. Economy of personal fatigue is a subject upon which Government officials have always had the reputation of being infallible authorities; but in work of so particular a nature as the transmission and reception of telegrams it becomes a subject well worthy of serious consideration as affecting correctness, and therefore of the value of the telegraph as an institution. Of these sounders the Post Office has at work a great many, and the number is continually increasing.

The sounder is constructed in various forms; but it consists essentially of an electro-magnet, through the coils of which the line current passes, and over the poles of which is held a soft iron armature. As the poles become magnetic, the armature is attracted, and in approaching the poles is stopped by a suitably arranged anvil, upon which it strikes with a sharp noise. On the cessation of the current, a reacting spring draws back the armature, which strikes on a second anvil with a less sharp noise. The difference between the two sounds and the duration of time which elapses between them enables the operator to recognize the signals.

Single-needle instruments are used to some extent still, especially on those lines which are worked at the railway stations. The needle system was the first telegraph invented in England, and it still asserts its claims for simplicity and ease of manipulation.

The single needle instrument is shown in Fig. 5. It consists of a vertical galvanoscope, the needle of which is limited in its motion between fixed stops, and of a sending handle or key, by which the current may either be cut off or reversed. When the handle is at rest—that is, upright — the battery circuit is interrupted; when turned to the right the positive, and when to the left the negative current is sent. Thus the needle of the galvanoscope can assume either one of these positions at the will of the sender, viz. upright, deflected to right, or deflected to left. The instrument is usually arranged in a compact case, with a desk in front for holding the message form.

FIG. 5.

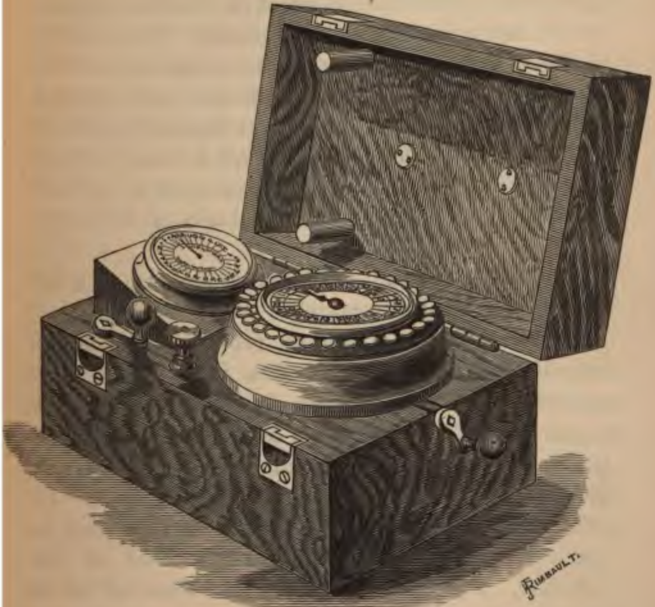


The deflections are interpreted in the same way as the alphabet, a right-hand deflection representing a dot, a left-hand deflection a dash, and the central position a space.

Wheatstone's A B C Instruments.—The instruments used on nearly all, if not all, private lines, are those constructed by Sir C. Wheatstone. The instruments at each station usually consist of a communicator and an indicator, the most recent and compact form of which is shown in Fig. 6.

The communicator consists of a permanent steel magnet, before the poles of which a soft iron armature

FIG. 6.



is rotated by continuously turning the small handle in front of the instrument. On the top is a dial-card, with alphabet, &c., opposite to each letter of which is a small finger-key. When a letter is to be telegraphed, its corresponding finger-key is depressed, and the index or pointer which moves over the dial-card allowed to rotate until it stops at the letter in question, which causes a certain number of currents to be sent into the line, and which propel the pointer of the receiving instrument correspondingly. When another letter is to be sent, its button is depressed in the same way, the handle in the front being still rotated. The receiver of this instrument has two electro-magnets, between which a polarized armature oscillates, and moves a small ratchet-wheel or propelment between two fixed springs, by which the wheel acquires a rotary motion. A pointer in the axis of the wheel indicates on a dial-card placed at an angle at the back of the communicator.

The bell is maintained by clockwork, released by the action of an electro-magnet.

Any person who is able to read, is able, almost immediately, to manipulate this instrument. The operator has merely to touch, in succession, with the fingers of one hand, the keys corresponding with the letters forming the message which he wishes to transmit, whilst he turns the handle with the other hand. In order to receive a message, the operator has only to watch the letters pointed to by the hand of the indicator. The correspondence can be carried on at about twenty words per minute.

The electric currents which actuate this instrument being produced by the employment of a permanent magnet, instead of a voltaic battery, chemical preparations are not required, and the instrument is therefore ready to be put in action at any moment, at whatever distant place it may be removed to, and however long it may have been in disuse.

The coils of copper wire in the interior of the instrument, the line wire, and the coils of the indicator at the distant station, form an uninterrupted metallic circuit, so that *no working contacts* whatever occur, as is the case in other step by step instruments.

In addition to the instruments which I have enumerated as being those most commonly in use, there are many very beautiful inventions which have also been used and done valuable service; amongst these is the printing telegraph of Mr. D. Hughes, which is still employed on the lines between France and England, but not now by the Post Office.

When we reflect on the state of telegraphy forty years ago, on the rapidity with which it has attained its present gigantic development, and on the active and intelligent minds which are still busily at work in its service, we may conclude that we are still far from seeing all the wonders it is destined to effect.

AGRICULTURAL MACHINERY.

By Prof. Wrightson (The Agricultural College, Cirencester).

In so short a space as is here allowed me, to give a general and, at the same time, graphic idea of agricultural machinery is a somewhat difficult task. The Wolverhampton Implement Catalogue of the Royal Agricultural Society's show (1871) contained 7650 entries, distributed through 363 stands, and these multifarious exhibits entailed miles of shedding.

The extensive works of the Messrs. Howard, of Bedford; Ransome, Sims, and Head, of Ipswich; Clayton and Shuttleworth, of Lincoln; Fowler and Co., of Leeds; Crosskill, of Beverley; Barford and Perkins, of Peterborough, and a host of others, employ their tens of thousands of skilled mechanics. Steam ploughing, steam threshing, reaping by machinery, drilling by machinery, and the numerous less complicated, but constantly recurring agricultural operations, need only to be mentioned to give some idea of the importance of our subject.

The development of this branch of mechanical industry has been characterized by great rapidity. In 1731, Jethro Tull first drew attention, in his 'Horse-hoeing Husbandry,' to the importance of drilling root and corn crops. Many persons are living, who were born before Andrew Meikle had constructed the first threshing machine, and it was only in the year 1851 that the reaping machine appeared as a novelty at the International Exhibition. Twenty years ago steam cultivation was a mere experiment, and traction engines were unknown except upon some highly favoured occupations. Taking the annals of the Royal Agricultural Society as a safe guide in tracing the development of this branch of engineering, we find that at the first Exhibition of the Society at Oxford, in 1830, there were twenty-three exhibitors of implements:

In 1840,	at Cambridge,	there were	36	exhibitors.
„ 1848	„ York	„	146	„
„ 1869	„ Manchester	„	366	„
„ 1871	„ Wolverhampton	„	332	„
„ 1873	„ Hull	„	298	„
„ 1874	„ Bedford	„	346	„

So great has been the number of applicants for places at these shows, that the Society has lately been obliged to issue restrictive orders to check the growing disposition to exhibit articles whose connection with agriculture appeared somewhat remote, and this difficulty accounts for the slight falling off after Manchester.

English manufacturers not only supply the markets of Europe with agricultural machinery, but their implements are the models from which foreign engineers work. Every French, German, or Italian treatise on agriculture abounds in drawings of English ploughs, harrows, &c., and the names of our best makers are as familiar in those countries as they are in England. Machines have also been adapted for the requirements of growers of cotton, sugar, oil, and other products, the cultivation and preparation of which cannot be included in my programme. I must confine myself to the implements used in British farming, and in treating of them, want of space forbids any attempt to describe their construction. Descriptions indeed are unintelligible without drawings, and would be omitted alike by the professional and non-professional reader. The student who wishes to wade through detailed description must seek consolation in Scott Burn and Stephens' 'Book of Farm Implements,'* and in the painstaking reports which have appeared year by year in the Journal of the Royal Agricultural Society.

It will be well to bear in mind that agricultural machinery can never increase and cheapen the produce of the earth, in the same manner as manufacturing machinery has increased and cheapened the products of human skill. No machinery can multiply the earth's powers of production, still less can it increase the number of our harvests. No cultivation will be followed with greater success, measured by gross return, than that effected by the spade, and for this reason, we cannot expect a large increase of productive power per acre from the application of steam to agriculture. Here then we have a fundamental difference between the function of agricultural and manufacturing machinery, for the latter may be employed so as to multiply production until prices sink to a minimum (as for instance our penny papers), while the profits of capitalists and the wages of labourers are fully kept up or increased. In agriculture a different law obtains, for here, after a certain and not very advanced stage, increasing the labour does not proportionally increase the produce; "doubling the labour does not double the produce; or to express the same thing in other words, every increase of produce is obtained by a more than proportional increase in the application of labour to the land (J. S. Mill)." This, "the most important proposition in political economy," must not be lost sight of. It helps us to arrive at a sound conclusion as to the functions of machinery in agriculture, and to show us how far this may be looked to as a means of assisting the cultivator of the soil. What then are the advantages which agriculture derives from the introduction of improved machinery? I propose to answer this important question at length, before passing on to the consideration of implements and their various effects upon agricultural industry.

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* 'The Book of Farm Implements,' by R. Scott Burn and Henry Stephens, published by Wm. Blackwood and Sons, London and Edinburgh.

1st. Improved machinery enables the cultivator to take full advantage of propitious seasons. Everyone practically acquainted with agriculture knows how much the success of all operations depends upon their being well timed, and this is alike true of the cultivation of the land, the management of growing crops, harvest operations, and the preparation and marketing of crops.

2nd. Improved machinery gives the farmer power to cultivate the soil deeply, to break it up more effectively than could have been done by horses. This has been proved over and over again upon clay lands, where through this means both a larger area of corn has been sown, and a larger yield per acre obtained.

3rd. A greater precision has been thrown into field and barn work, and all operations are more perfectly performed than formerly.

4th. The cost of some operations has been diminished, especially in the harvest field and barn, although in many cases the advantage has been seen more in increased efficiency than in diminished cost.

5th. The teachings of science have been rendered practicable by machinery, which enables the farmer to follow them in the cultivation and manuring of the land, and the feeding of stock.

These advantages have been accompanied by an increased intelligence on the part of both farmers and labourers, and the investment of a larger amount of capital in the cultivation of the land.

Some of the innovations introduced by improved machinery, such as that of drilling corn, owe their position to causes which must appear puzzling to an outsider. Drilling for instance is slower, more expensive, and in many cases not more effective than the old broadcast method of distributing seed; and yet it has almost completely superseded the older plan, for reasons presently to be considered. Steam cultivation again is often more expensive, but at the same time is more effective, than horse tillage. Reaping corn, on the other hand, is both quicker and cheaper, but less perfect in its work than the old sickle. Hence a clear *difference* is observable between the functions of machinery when applied to agriculture, and when applied to other arts. In agriculture it, in a word, may be said to render the operations to which it is applied more *effective*, without quickening them or multiplying their results. In other arts machinery not only renders operations formerly done by hand more effective, but multiplies results to an almost infinite extent, while from the very nature of agriculture such an effect is not to be looked for.

Agricultural machines and implements are so multifarious, that, to facilitate their consideration, we must adopt some system of classification, and that which suggests itself as most promising is also most natural. We have in the history of every crop a ready means of dividing most agricultural implements into definite sections. 1st. There are implements for preparing the ground for the reception of the seed, or implements of cultivation. 2nd. For depositing the seed, such as sowing machines. 3rd. For manuring and for the after cultivation of the young plant, as manure distributors, and hoes of all sorts. 4th. For securing the crops, such as reaping and mowing machines, &c., to which may be added carts and waggons. 5th. For preparing the crops for market—barn implements. 6th. For preparing crops for home consumption by stock, such as mills, chaff cutters, and turnip cutters. 7th. Implements employed in estate work rather than in ordinary farming, such as for drainage, and dealing with wood and stone. 8th. Miscellaneous implements difficult to class with any of the preceding. 9th. All tools used as hand implements.

IMPLEMENTS OF CULTIVATION.

The plough, the harrow, and the roller were until recently the three instruments universally employed in agriculture, the plough being undoubtedly the most ancient as it is the most important of this triad. "I have found," writes Professor Rogers, of Oxford, in his 'History of Agriculture and Prices in England' (1259-1400), "no trace of roller or of harrow with iron teeth." Both these implements are figured in Markham's 'Complete Husbandman,' published in 1614. Professor Rogers also remarks that "the ordinary means by which our forefathers covered their seed was by bush harrowing; and nothing is more common in the accounts which have come under my notice than the purchase of thorns, black and white, for the express purpose of harrowing newly-sown tilth." In 1717, Edward Lisle published his work 'Observations in Husbandry,' but no other cultivating implements than the three already mentioned are described. These have all maintained their ground, and even yet are the only three cultivating implements used upon many farms. The most successful systems of steam cultivation have also adopted them, with such modifications as were necessary for the altered character of the power. We have then ploughs, harrows, and rollers adapted both to horse and steam power, to which we must add grubbers or cultivators, a class of implements of recent introduction, but which, when combined with steam power, threaten to seriously intrench upon the work which up to this time has been performed by the plough.

Ploughs and Cultivators.—A plough is an implement which inverts the soil. The share and cutter cut the furrow, the first horizontally, detaching it from the subsoil, the second vertically, while the mould board gradually turns over the furrow, leaving the under side at the surface and bringing the former surface beneath. The plough sole at the same time slides on the bottom of the furrow, and when the operation of ploughing has been repeated some hundreds of times at about the same depth, a "pan," or indurated crust of earth, is the result. This brief description of the essential work of ploughing shows at once the merits and the failings of the plough. No other horse-drawn implement more thoroughly aërates and pulverizes the soil; so completely cuts deep tap-rooted weeds, such as docks, thistles, and coltsfoot; gives such a deep and thorough movement to the soil, or so completely uproots the larvæ or pupæ of destructive insects.

The plough also is the implement for covering or ploughing in farmyard dung, for following after the sheepfold on arable land, and for breaking up grass or lea land for wheat. It would be impossible to cultivate fallows on clay lands, or to break up stubbles in autumn without it, and we should have no difficulty in pointing out other good offices in which the plough is indispensable. Still, it has failings, and these shortcomings have called forth the considerable class of grubbers afterwards to be passed in review. The first objection has already been touched upon. Repeated ploughings at one depth indurate the soil, so that it becomes difficult either for water or the fine roots of plants to penetrate it. The plough "slade" or "sole" is to blame for this, and accordingly ploughwrights have given much attention towards altering the structure, so as to dispense with the necessity of the sole. The plough of course must rest its weight on the earth over which it is drawn—hence the difficulty of doing away with a sole of some sort. The problem has however been solved by Mr. Pirie, who about six years ago brought out, in conjunction with Messrs. J. Fowler and Co., of Leeds, the Pirie plough. This is a double plough, or plough able to turn over two distinct furrows at once. Both ploughs are supported on a framework of iron, travelling on the wheels which take the weight of the implement. Two of these wheels run upon the unploughed land, while one runs in the furrow behind the ploughs, and by this arrangement much of the damage attributable to the plough sole has been avoided. The second objection to the plough is, that while inversion of the soil is desirable before winter, it is not so requisite, nay, is often positively injurious in spring. On light lands, spring ploughing dries them to such an extent, that "roots" do not subsequently thrive upon them. On stiff lands the effect of spring ploughing (following an autumn ploughing) is to bury all the fine soil, the result of the winter's frost and change of temperature, and to cover the surface with hard, unmitigated, unpromising clods. The third objection applies to that arch-enemy, couch. The plough unquestionably cuts the couch, and as couch, like many other noxious plants, suffers only a temporary inconvenience from the operation—each joint spreading and growing with renewed energy—the plough has been accused of disseminating couch.

These imperfections and faults have been well met by the large class of grubbers or cultivators already mentioned. The grubber is intermediate in its action between the plough and the harrow. Like the former, it moves the soil to a considerable depth and is furnished with points or shares. It has, however, no mould board or turn-furrow, and consequently, while it moves, it does not invert the soil. Any harrow in which the teeth are long and curved forward becomes a sort of cultivator, and indeed Finlayson's harrow, one of the first cultivators ever made, may for several purposes be so described. The modern cultivator, as represented by Coleman's, Clay's, Tenant's, or Biddell's implements, consists of a framework mounted on wheels, from which curved teeth or tines descend into the ground. These tines are usually armed with feet or shares, removable and exchangeable, which assist in the thorough movement of the soil. The teeth should have a good rake forward, to clear themselves easily of couch and clods; they should not be too close together for a similar reason; they should be so arranged on the frame, one behind or in front of another, that as the implement moves forward all the land may be moved, and they should be mounted on wheels sufficiently high to prevent clogging from the accumulation of weeds and earth. These implements are useful at two periods of the year; first after harvest, upon foul or weedy *stubble*, as a means of paring the surface, and thus effecting a separation between the couchy upper soil and the comparatively or perfectly clean under soil. This is well performed by Coleman's cultivator or Bentall's broad share, or even by a broad share attached to a common plough, and is infinitely preferable to at once ploughing the stubble and burying the weeds—which only succeeds for a time. The second season when these implements become useful is the spring, in the preparation of land for roots. For reasons already given, the plough is not desirable at that time, and the cultivator effects all requisite pulverization without either wasting moisture or burying the fine surface, the result of the winter's frost. I do not wish to lay down a "hard and fast line" in speaking of the relative use of ploughs and cultivators, still less do I wish to find myself writing in direct opposition to the practice of practical and money-making farmers. Some land may be advantageously ploughed in spring, especially land of intermediate character, neither very light nor yet very stiff. Such land will plough up friable and mouldy, still retaining sufficient moisture, and consequently may be ploughed without danger. As a general principle, however, and especially in late spring work, I prefer the cultivator. It is only fair to mention the objections used against horse cultivators by good farmers, namely, that they lose depth of tilth by an insufficient and incomplete movement of the soil, and secondly, that they encourage the growth of thistles and other tap-rooted weeds. With regard to the first objection, it is not *se which* involves the principle, but the power of the cultivator. It applies to horse cultivators, but not to similar implements drawn by steam power. The last is, I venture to think, a little fanciful, and also applies only to cultivators of bad construction. It is however certain that where couch is prevalent, the cultivator answers much better than the plough, for its teeth draw out the couch in long unbroken threads, while the plough minces them up into fragments, each of which is capable of propagation.

Harrows.—This class of implements need not detain us long. Harrows are useful for many purposes, and are manufactured of various sizes, weights, and strengths. The heavy drag harrow, for turning over clods under a July sun, is the heaviest variety; next come the ordinary seed harrows, for covering over newly-sown corn; thirdly, grass seed harrows of still lighter construction, made to harrow in small clover and grass seeds upon young barley. There are also chain harrows, formed of series of links, first brought out by Cartwright, and which are useful for covering grass seeds, for brushing in farmyard manure upon grass land, and also for collecting couch together, after it has been brought to the surface, upon arable land. Harrows are the farmer's rakes, by which the surface is made fine and smooth, and the seed is covered.

Rollers.—Rollers have been much improved, since the time when the bole of a tree was extemporised into the required implement. Not only has the simple expedient been exchanged for a well-made iron cylinder, but other improvements have been effected in the structure of these implements. Every farmer nowadays has his "ring-roller," either in the form of a Crosskill or a Cambridge roll, and the plain iron cylinder is now little used, except to smooth pastures intended for mowing.

The old wooden roll also still holds a place in the modern farmery, for such purposes as flattening down turnips, ridges, or new-sown barley, in order to diminish evaporation, which is always most rapid from a rough surface. There are then four varieties of this implement which claim attention, namely, Crosskill's clod crusher, Cambridge's roller, the plain iron roll, and a light wooden roll. The first was brought out, as its name implies, to help the clay-land farmer. Every season, however, teaches us that clods are scarcely well treated by forcibly crushing them. Autumn cultivation and properly timed operations will best overcome the natural difficulties which attend the management of clay soils, but to attempt to grind down a clay by means of powerful rollers is a mistake. Accordingly the Crosskill roller has not found much favour at the hands of clay-land farmers, but has obtained a firm footing upon the light lands of the country, not as a clod crusher, but as a land presser and consolidator. The Cambridge roller has a similar task, and both are used to "firm" land for wheat upon newly-ploughed leas, and to press the ground once more around the roots of young wheat in the spring, after the heavy action of the frost has loosened the soil and half thrown out the young plants. These implements differ from the common cylindrical roller by being composed of a number (twenty-three in the case of the Crosskill) of rings strung upon a spindle. In the Crosskill roller, each ring or wheel is notched or serrated, and each notch is pressed with great effect either into the top of an obdurate clod or into the runs of wireworms. The ring of the Cambridge roller is more like a circular knife, and cuts its way through the clods, or leaves fine groove-like markings where the ground is sufficiently pulverized. This peculiarity renders the Cambridge roller useful in the sowing of clover and other small seeds, for by first rolling barley land with this implement, a series of small grooves is formed into which the clover seeds fall, and the operation of sowing is followed by the use of a brush harrow, which sufficiently buries them. I have no great faith in rollers as pulverizers, although I value them as land pressers. Often while they render the surface fine, they consolidate the subsoil, and should the land subsequently be ploughed, it will be found to be hard and livery instead of friable.

Tillage by Steam.—I have already mentioned that the plough, cultivator, and harrow have been adopted by our leading promoters of steam cultivation. Rotary diggers have been a favourite theme of writers, but as yet the most successful efforts towards the employment of steam in agriculture have been properly spoken of as steam ploughing, steam cultivating, and steam harrowing. Again, these implements are in all the systems in general use drawn over the land by steel ropes, the engine standing on the headland. Mr. Howard attributes the small progress made by the Americans in steam cultivation to the attempt there so frequently made of substituting the iron for the living horse, by carrying the engine over the land with the cultivating implements following in the rear.

Messrs. J. Fowler and Co., of Leeds, occupy a leading position among the manufacturers of steam tillage implements. The newest and most powerful set of steam cultivating tackle (Fig. 1) requires two engines, one on each headland, each of which alternately draws the cultivating implement across the field. Each engine is provided with a winding or hauling drum, which in turn pulls the implement and pays out the slack rope. This system is both simple and effective.

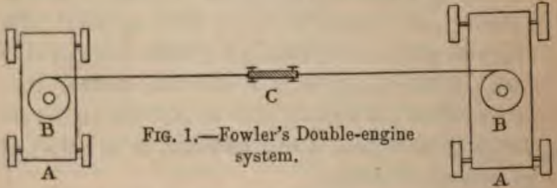

FIG. 1.—Fowler's Double-engine system.

The implement is drawn with considerable velocity—often much faster than a man can walk—and the steam drag or harrow will pass over from fifty to sixty acres of land per day. Fowler's double-engine system appeals to large capitalists, but the same firm also provides good single-engine sets for the use of smaller occupiers. The single-engine system (Fig. 2) requires an engine on one headland and a self-moving windlass on the other. The engine is provided with the patent Burton clip drum, capable of hauling the cultivating implement backwards and forwards between the engine and windlass. Both engine and windlass travel along the two headlands opposite each other. A third system is offered, in which the engine remains stationary, and the rope is arranged in an irregular triangle or square, while the implement passes to and fro between two fixed anchors, rendered movable at pleasure. This is called the "roundabout system," because the rope is carried around anchors and encloses the space to be cultivated. The several systems thus slightly described will be more easily understood by reference to the accompanying diagrams.

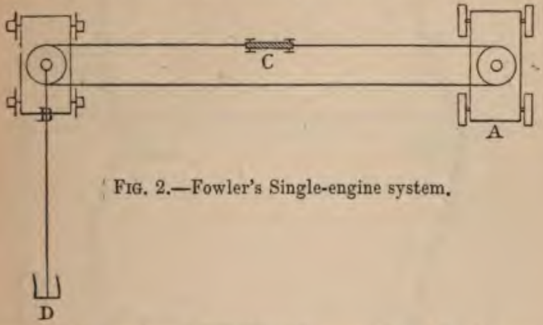

FIG. 2.—Fowler's Single-engine system.

Messrs. J. and T. Howard, of Bedford, supply different sets, adapted for both large and small holdings, differing in many details from the last, but corresponding with them so far as the principle of hauling is concerned. Mr. Smith, of Woolston, adopts the "roundabout system" in arranging the rope, and abjures the plough for the cultivator. He prefers smashing up the land to ploughing it, and his system is in high favour with the smaller holders of land. One of the main advantages of the so-called roundabout

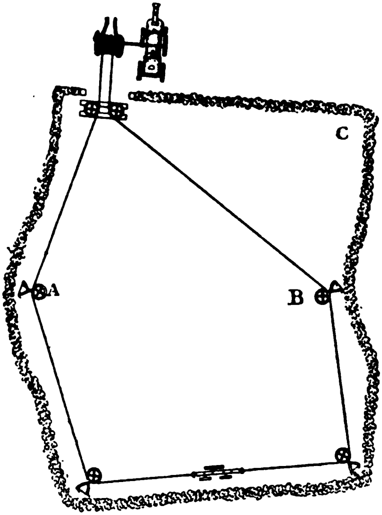

FIG. 3.—Showing general arrangement of Roundabout system.

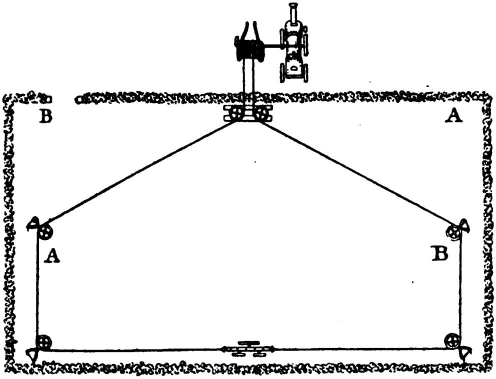

FIG. 4.—Showing general arrangement of Roundabout system.

plan is that it enables the farmer to employ any ordinary traction engine for ploughing purposes, and thus reduces the amount of capital required in commencing steam cultivation.

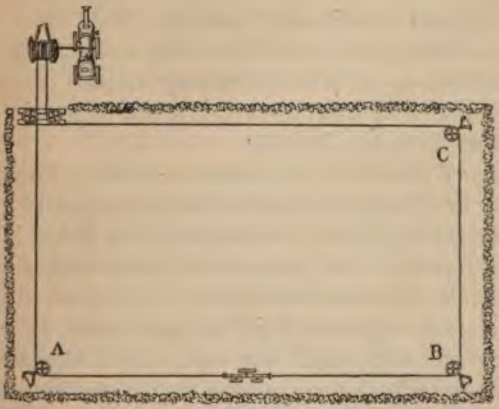

FIG. 5.—Showing general arrangement of Roundabout system.

The following particulars, taken from one of the Royal Agricultural Society's Implement Catalogues, will give the reader a good idea of what is included in a set of steam cultivating implements. Messrs. J. Fowler and Co.'s double engine, 20 horse-power set, consisting of a pair of 20 horse-power self-moving engines with single cylinders, fitted with single winding drums, 800 yards of best steel wire rope, and working a thirteen-tined cultivator, costs 1975*l.*, and with six-furrow balance combined plough and digger in addition, 2070*l.*

Messrs. J. Fowler and Co.'s 12 horse-power set, consisting of a pair of 12 horse-power self-moving engines, &c., as before, with nine-tined turning cultivator and five-furrow balance plough, costs 1447*l.* 10*s.*

The Messrs. Fowler also supply a single engine set, with seven-tined balance cultivator and four-furrow plough, and all necessary machinery, for 884*l.*; and an 8 horse-power set for 758*l.* Also a combination of machinery, in which an ordinary agricultural engine is employed, with detached windlass and ropes, on the roundabout system, for 375*l.*

Mr. William Smith's steam cultivating machine, made by Messrs. Barrows and Stewarts, consists of a stationary engine and detached windlass tackle. The set, involving a 12 horse-power engine with double cylinders, a two-drum windlass, on four wheels, driven by a connecting shaft with universal joints, or by a rigger and belt; steel wire rope, snatch block, claw anchors, dead anchors, porter's tools, &c., with a five-tined Woolstan cultivator, fitted with turning bow, price 486*l.*; or with a three-tined cultivator, 500*l.*

Messrs. J. and F. Howard, of the Britannia Works, Bedford, entered at Wolverhampton a pair of patent self-propelling engines, fitted with winding drums for working to and fro, or double-action implement. These engines were of novel construction, and were the first portable engines fitted with Messrs. Howard's patent safety boiler. The same firm set down a 12-horse double drum and anchor set, working on the "skew" plan, furnished with 1600 yards of ¾-inch wire rope, a five-tined reversible cultivator, and all necessary adjuncts, for 660*l.*; a 10-horse set, price with five-tined reversible cultivator, 500*l.*; and a set to be worked by an ordinary agricultural engine, with ropes arranged on the roundabout plan, for 250*l.*

It may be doubted whether the employment of steam in the cultivation of the ground effects a direct saving to the farmer in the cost at which the operation is performed. Horse ploughing can be done on moderately light soils at 8*s.* per acre, and probably for as little or less by bullocks. In parts of Norfolk, Lincolnshire, and on the wolds of Yorkshire, a boy and two horses can plough their two acres per day; and Mr. Howard, of Bedford, recently told the Farmers' Club in London that the American farmer expected even a larger amount per day from each team.* At 3*s.* per day for each horse, 2*s.* for the lad, and 1*s.* for the use of the plough, the cost of ploughing in this case would be only 4*s.* 6*d.* per acre; and it is difficult to see how, with coals at a high price, the work could be done for less by steam. When, however, we turn to the stiff clays of Kent the cost of ploughing is greatly increased by the employment of four horses and the much less area ploughed in the day. On such soils four horses, one ploughman, and one driver cannot be expected to get over more than three-quarters of an acre per day, or taking the same range of prices for both horses and men, 18*s.* per acre. No doubt ploughing under such circumstances frequently costs a greater sum, and probably finds its maximum price at 25*s.* per acre. Under such circumstances the employment of steam will effect a direct saving, and there is also a class of work involving much power which could not be performed by horses and yet can easily be accomplished by steam.

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* The rapid increase in the value of horses and of manual labour during the last three years will to some extent modify the conclusions above arrived at.

Mr. Swanwick, of the College Farm, Cirencester, has furnished me with the following estimates of the cost of steam ploughing and cultivating done by contract upon free working land in the autumn of 1872:

Descriptive No. of Field.	No. of Acres.	Kind of Work.	Contractor's Account.			Carting Coal and Water.			Tons of Coal.	
			£	s.	d.	£	s.	d.	tons.	cwt.
1	21	Steam worked, at 26s. per acre, which includes ploughing, cultivating, and two draggings	27	6	0	2	0	2	6	1
5	34	Steam worked, at 26s. per acre, which includes ploughing, cultivating, and two drag harrowings	45	10	0	3	3	1	9	18
7	22	Twice dragged, at 6s. per acre	6	12	0	0	7	3	1	13
15	42	Once cultivated, at 7s. „	14	14	0	2	4	9	3	6
15	44	„ „ 6s. „	13	4	0		—		—	
	2	Twice „ 12s. „	1	4	0		—		0	7
16	19	Steam worked, at 18s. per acre, which includes ploughing, harrowing, and cultivating	17	2	0	2	11	4	3	6
18	18	Steam ploughed, at 9s. per acre	8	2	0	0	8	6	2	4

It will be seen that the prices fixed by contract do not include either coal or expenses connected with hauling water.

Having hazarded an opinion, that upon ordinary moderate and light soils it is difficult to show a direct economy from the employment of steam, I turn to the Report of the trials at Wolverhampton in 1871, *given* in the 'Journal of the Royal Agricultural

Society.' The writer, Mr. J. A. Clarke, has paid especial attention to the whole subject of steam cultivation, and in the following remarks he not only throws light upon the subject in hand by a distinct expression of opinion, but gives also a good idea of the progress which has been made in steam cultivation within the last few years. It must, however, be remembered, that in all show-yard competitions, the implements are new and of the very best type, while the men who are sent with them are thoroughly trained to show the implements under their charge to the very best advantage. The same implements in the hands of rural engineers could not be expected to turn over the ground as rapidly as we see done in the fields devoted to competition, any more than the thrashing machines turned out by our many good manufacturers fulfil the quantum which they are advertised as capable of achieving.

At the earliest trials of the Royal Agricultural Society (1856), Mr. Amos drew up tables to show the comparative costs of ploughing by steam and by horses. In these tables the money cost of steam ploughing is 7*s.* 2½*d.* per acre. The judges are of opinion that the cost of the like work by horse power would be at least 7*s.* per acre. Mr. Amos however had in this calculation favoured the steam power by allowing too small a sum for wear, tear, and interest, and assuming too large an annual acreage. At Chester the judges allowed wear and tear at 15 and interest at 5 per cent., spread over 200 working days in the year. They reported that Fowler's apparatus ploughed light land at the rate of 7¾ acres in ten hours, and heavy land at the rate of 5 acres in ten hours, the total cost being in the first case 6*s.* and in the latter 9*s.* 2*d.* per acre. Our estimate, they said, of the quality and value of the work thus performed is, that the light land could not have been done by horse-power for less than 8*s.* per acre; that the heavy land could not have been ploughed for less than 12*s.* 6*d.* per acre, and that the deep trenching could not have been done by horse ploughing at all. In the same trials the Woolston implements exhibited by Messrs. Howard cultivated heavy land twice over, at the rate of 3½ acres in ten hours, for a total cost of 12*s.* 9*d.* per acre, while to effect, say the judges, a similar result with the ordinary implements and horse-power, three distinct operations would be required, which could not be performed at less than 18*s.* 6*d.* per acre. The judges concluded that the prize machine was able to turn over the soil in an efficient manner at a saving, as compared with horse labour, on light land of 2½ to 25 per cent.; on heavy land 25 to 30 per cent.; and in trenching 80 to 85 per cent.* Other instances are given in which the comparative cheapness of steam is clearly shown in show-yard trials; but in spite of these favourable examples, I am disposed to consider that in the field, the advantages of using steam in the cultivation of the soil are not to be looked for in a direct saving of expense, unless it be upon very stiff soils or where the work is much deeper than that of ordinary ploughing.

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* J. A. Clarke's Report, 'Journal of the Royal Agricultural Society,' vol. xvii. part ii.

The advantages of steam cultivation, however, are numerous, and especially appeal to the occupier of stiff soils. They may be thus summarised:

1. Cheapness.
2. The necessary cultivation performed at the time when it is most useful.
3. Relieving of the land from the treading of horses.
4. A deeper tillage can be effected.
5. A larger breadth of wheat may be cultivated.
6. More abundant crops.

Of these, the second is among the most important, and might induce me, did space permit, to descant upon the advantages of autumn cultivation, working clay lands at dry seasons, and being beforehand with work. It will, however, be noticed that the above advantages are connected essentially with clay lands, and cannot affect the holder of light soils, who is less careful to have his land worked at a particular time, who does not believe in the advantage of very deep culture, and who treads his land with sheep in order to give it the requisite firmness for growing corn. The most successful attempts at steam cultivation upon light lands have been made upon the principle of employing rapidly moving wide implements, similar to Messrs. Fowler's steam "drags." These cover a very large area in the course of the day, and are as effective upon light soils, in the spring, after winter ploughing, as any horse cultivator. It is stated on good authority that steam cultivation enables the farmer to dispense with from one-third to one-fourth the number of his horses, and the putting down of an agricultural horse is calculated to effect a saving of about 44*l.* per annum.

SOWING IMPLEMENTS.

Drills, &c.—Jethro Tull published his invention of the drill in 1730–1. He writes: "When I was young my diversion was music. I had also the curiosity to acquaint myself thoroughly with the fabric of every part of my organ; but as little thinking that ever I should take from thence the first rudiments of a drill, as that I should ever have occasion of such a machine, or practise agriculture; for it was accident, not choice, that made me a farmer, or rather many incidents, which could not then possibly be foreseen." Profits being at that time small, chiefly, it appears, because plough servants began "to exalt their dominion over their masters, and all mine being of that sort, Mr. Tull turned his attention to the subject of economising seed. He practised himself in discriminating good from bad seed, and subsequently found, "by many trials, that scarce any, even of the best, would succeed unless covered at a certain exact depth." This led him to employ people to make channels, and sow a very small proportion (of seed) therein, and cover it exactly. "This way succeeded to my desire, and was in seed and labour but a fourth part of the expense of the common way, and yet the ground of seed was better planted." It appears that through the negligence or jealousy of his labourers, this experiment failed, and Tull adds: "I was forced to dismiss my labourers, resolving to quit my scheme, unless I could contrive an engine to plant St. Foin more faithfully than such hands would. To this purpose I examined and compared all the mechanical ideas that had ever entered my imagination, and at last pitched upon a groove, tongue, and spring in the sound-board of the organ. With these a little altered, and some parts of two other instruments, as foreign to the field as the organ is, added to them, I composed my machine. It was named a drill; because when farmers used to sow their beans and peas into channels or furrows by hand they called that action drilling."

In the long interval of years between 1730 and 1871 the drill has undergone many improvements, has assumed many forms, and has established itself as one of our most indispensable farm implements. It has been adapted for sowing all seeds, from clover to beans, at any required quantity per acre, and for depositing manure with the seed, while latterly the water drill has been devised, enabling the farmer to sow turnips and swedes with manure suspended in water, and applied at the rate of from 200 to 600 gallons per acre. Recent catalogues contain references to the following classes of drills:

Corn and seed drills.
General purpose drills.
Hand drills and gapping drills.
Turnip drills.
Turnip and mangold drills.
Drill and land-pressers.
Manure and seed drills.
Potato drills.
Rye grass and small seed drills.
Ridge drills.
Water drills.
Barrow seed drills.
Cup drills.
Dibbling machines.

Messrs. Garrett and Sons, of Leiston, Suffolk, occupy a very leading position as drill makers, and among other well-known manufacturers may be mentioned Mr. James Coultas, Spittlegate, Grantham; Messrs. Hunt and Pickering, Leicester; Messrs. Hornsby and Sons, Spittlegate, Grantham; Messrs. Holmes and Sons, Norwich; Messrs. Reeves and Son, Westbury, Wiltshire; Mr. W. S. Underhill, Newport, Salop, &c. &c.

Drills are now in universal use in England, and are rapidly becoming so in Scotland. The Scotch and north of England farmers have, however, adhered with great pertinacity to the older system of hand sowing, and as this system is still recognized as useful under certain circumstances by all farmers, it will be interesting to inquire into the relative merits of hand-sowing or broadcasting *v.* sowing by the drill.

In the case of all root or fallow crops, i. e. crops which take the place of the old bare fallow, once universally used as a means of cleaning and renovating land, the advantages of the drill are perfectly clear. A "fallow" is not effective unless it leaves the land both rich and clean, and when a fallowing or cleaning crop is sown, both objects must be kept steadily in view. The first is accomplished by liberal manuring and feeding the crop upon the land; the second must be secured by cleaning processes before sowing and subsequent interculture. This last requirement involves sowing in rows and the consequent employment of a drill. In the sowing of cereal crops much may be said in favour of broadcasting. (1) Supposing the land to be clean (free from weeds), broadcasting ensures a very equal distribution of seed, each plant being (supposing a perfect system of broadcast sowing) equidistant from its neighbours. (2) It is a much more rapid and cheaper method of sowing—one man being able to sow 15 acres per day. (3) When the furrow is well laid for the purpose, i.e. presents a good "seam" for the reception of the seed, or when the ribbing plough is used, broadcasting is as effective as drilling. (4) Upon wet and heavy soils the trampling of horses and the passage over the ground of a heavy implement are avoided; on the other hand, while drilling gives the plants a larger amount of room between the rows, they are crowded *in* the rows. It is slower, and more expensive than broadcasting. It acts injuriously upon wet, stiff clays. To all these objections the important fact may be urged, that drilling has triumphed over broadcasting, and has thus proved its excellence. Drilling also possesses the following substantial merits. It ensures the depositing of the seed at a uniform depth; allows of horse and hand-hoeing (interculture), while a saving of seed is effected.

It is difficult to see how wheat could be sown except with the drill in the south of England, where the general system is to sow upon a surface pressed firm and flat by the Crosskill or Cambridge roll.

In the above list, seed barrows are noticed. These are upon the broadcast principle. They consist of a long seed box, through which runs a spindle furnished with revolving brushes placed at intervals. Opposite each brush are holes in a metal plate through which the small seeds are perpetually brushed; and falling on to a distributing board, they find their way to the ground, and are subsequently harrowed in. This is a favourite method of sowing clovers and rye grass, and it is occasionally used in sowing barley.

The term "dibbling" expresses the process of sowing in holes, as when potatoes are planted in a garden. This process has been applied to corn, and many persons believe in its advantages. I am inclined to think that although this method of sowing may be used with beans, it cannot he successfully and generally applied to the sowing of cereals. Upon very good land and for very early sowing dibbling wheat may succeed, but it is at best rather hazardous, and must not be attempted on inferior soils, or when the season is late. Hand dibblers of very simple construction may be used for sowing mangold or beans, but I cannot recommend the ordinary farmer to purchase those elaborate machines exhibited in our showyards for this purpose. It appears to me an unwarrantable outlay of capital in a department which is liable to absorb more than its share. I must however mention Messrs. John Freer and Co.'s Patent Grain and Seed Dibbling Machine with six dibbling wheels, and capable of dibbling every variety of grain and seed, price 59*l.*

IMPLEMENTS USED IN THE AFTER CULTIVATION OF CROPS.

Hoes.—Hand- and horse-hoeing are both in constant requisition during summer, and it has been often remarked that in order to realize the advantages of drilling corn, the horse-hoe must follow the drill. These machines are sent out by most drill makers, and are constructed for following the drill in due time.

Messrs. Garrett furnish such hoes at from 17*l.* to 20*l.* each, provided with travelling wheels having the same spread as a drill, and with steerage for guiding the implement. The hoes are composed of iron stalks attached to the frame, and turning at right angles so as to form a cutting knife at their lowest extremity. These knives can be adapted to the work of hoeing root crops as well as grain. The numerous "scufflers" or horse hoes adapted for working soil between potato and turnip rows with a single horse do not require a lengthy notice. They consist of a broad share with two following hoes, and are expansive, so as to take a wider row if necessary. Three or four are required on an average-sized farm, and they are kept constantly at work throughout the summer clearing the root crops.

IMPLEMENTS USED IN THE HARVESTING OR SECURING OF CROPS.

Reaping and mowing machines claim a first place among the class of implements employed in the harvesting of crops. They are sufficiently novel to be interesting, and rank in importance with the threshing machine and drill.

The economy of using reaping machines is most evident, as they are now turned out so perfect that the old objections that they cut off heads close to the neck, and made untidy work, cannot be brought forward. They are now made to cut the heaviest crops of corn around Spalding, in Lincolnshire, while the mowing machine is employed upon the rankest grass crops produced by the use of sewage, sometimes 7 to 8 feet in length. They may also be used for beans, and hence the objection that machines fail to cut the heaviest crops falls to the ground. When corn crops are much twisted and laid flat with heavy rain, they present the greatest difficulty to reaping machines, but it is seldom that a crop is so severely affected that the implement cannot cut at least partially round the field, say two sides or three. A good improvement to meet this difficulty has been suggested by Mr. A. Hughes of Brampton Arle, Market Harborough, who has patented a comb which precedes the machine and lifts the flattest laid corn so that the knife can act upon it. The solid advantages of reaping corn by machinery may be thus summarised:

1. It acts as a wholesome control upon the labour market, at a time when labourers are apt to be exacting to an unreasonable extent.
2. It finds employment for horses at a period when they would without it be idle.
3. It enables the farmer to cut his corn when it is in the greatest perfection.
4. It diminishes risk by shortening harvest.
5. Machine-cut corn will be sooner ready for carting than the same corn if hand cut.
6. It is the cheapest method of cutting corn.

All these considerations are so important, that they have at once secured these machines a place in all good lists of requisite implements.

I cannot refrain from glancing at the history of a machine which has so benefited the agriculturist. Its first appearance was as a mechanical novelty at the International Exhibition of 1851, when it was introduced by Mr. McCormick, an American. Public attention being attracted, controversy was soon stirred up, and it was shown in the succeeding year that the Reverend Patrick Bell, of Carmylie, Forfarshire, had invented a very similar machine, which had been working upon his brother's farm for the past fourteen years, at Inch-Michael, Carse of Gowrie. Mr. Slight, of Edinburgh, who made this communication, also stated that four specimens of this machine had been sent out to America, and the principle upon which the new American reaper was constructed showed clearly that the Bell reaper was the model from which it had been taken. This discovery turned attention to Mr. Bell's reaper, which now entered into successful competition with McCormick and Hussy's machine, manufactured by Crosskill, of Beverley. The effect was that many of Bell's machines were made, and had a large sale in Scotland, until the old rival, the McCormick, again came into competition, with numerous improvements, under the name of Burgess and Kay's reaping machine, and firmly established itself as the most perfect implement of the kind. Samuelson's machine, brought out in 1862, formed the next important step, and had the advantage of cheapness, lightness of weight, draught, and simplicity in its mode of working, having no straps about it. Later on, Messrs. Hornsby, of Grantham, secured the first prize of the Royal Agricultural Society with an implement similar in many respects to Samuelson's, and this having received so high a commendation may be fairly considered to have earned a first place. The names of Cuthbert, Bamlet, Woods, Brigham and Bickerton, as well as other manufacturers, are also associated with excellent reaping machines.

Reaping machines either deliver the cut corn behind the implement or at its side; hence we have back-delivery and side-delivery reapers. Back delivery is effected by a tipping-board, which, after receiving a sufficient quantity of corn to make a sheaf, is "tipped," and allows the corn to slip off behind, the board immediately resuming its former position. These implements cost less money than side-delivery reapers, and are very portable and suitable for small farms. Side-delivery reapers either deliver the cut corn in a continuous swathe or in sheaves ready for tying up. The first class is represented by Burgess and Kay's and Crosskill's reapers, and is best adapted for cutting barley when it is not intended to tie up the crop into sheaves. The second class, represented by Samuelson and Hornsby, is best suited for wheat, or any crop which is to be tied up. There are also combined reapers and mowers, but these are not to be recommended on large or even ordinary sized farms. The difference between mowers and reapers consists in the apparatus for delivery, which is not required in the former. All that is wanted in cutting grass is a knife, so that when cut it immediately falls over and behind the cutting and advancing knife. In reapers the corn falls on to a receiving board of some kind, where it is delivered either at the back or side. The knife is the most important part of any reaper, and, without pretending to give a detailed description, I may say that it consists of a series of triangular blades or teeth riveted on to an oscillating iron plate or rod. The knife works between a series of stationary finger pieces, and a rapid oscillating movement is communicated to it by means of a crank, deriving its rotary action from travelling wheels furnished with internal gearing which engages with a small pinion wheel. Thus a rapid movement is obtained that is readily communicated to the crank, and from the crank to the knife. A good reaping machine, with 5-feet knife, will cut its acre per hour with ease, and will cost, in the case of Hornsby's machine, about 28*l.* The work of taking up and tying is usually let at from 4*s.* to 5*s.* per acre, and where a force of people is required to keep up with the machine, nine men, nine women, and nine children, will tie up and stook, gather and make bands, after Burgess and Kay's reaper (Mr. Jacob Wilson).

The horse rake is a second important help in the harvesting of hay and corn, and in the former case the hay tedder is useful. Mr. Harrison, C.E., when at Frocester Court Farm, Gloucestershire, showed clearly the immense saving effected in hay harvest by the use of the mowing machine, the horse rake, and the hay tedder. The last-named implement must, however, be employed with caution, for although useful in making old land hay, it breaks the leaves of clover, and thus injures the value of the hay. The straw elevator, an implement originally intended as an adjunct to the threshing machine, has been of late used in the harvest field. It is set down near a rick in process of building, and may be employed to lift sheaves from the ground to the top of the highest rick, thus saving much extra labour in forking.

Carts and Waggons.—In Scotland and the North of England single horse carts are almost the only vehicles at work upon farms. In the south, waggons are in great favour, although single and double horse carts are also in requisition. Keen discussions have often taken place as to the relative merits of carts and waggons, but wherever a fair contest between the two methods of carrying has been instituted, the cart has invariably come off victorious. For general purposes I incline to the opinion that the cart is the best, but in hay and corn harvest the waggon shows to advantage. Especially in hay harvest, it may be remarked, that waggons often enable the farmer to save his crop, as they are capable of lifting such large weights of hay from the field to a place of safety. A light waggon, indeed, is useful upon any farm. Every farmer requires long carts, and short or tilt carts, the first for carrying corn, and the second for dung, or for roots, &c. In Scotland, a good plan prevails of having a long and a short body to each pair of wheels. The wheels being by far the most expensive part, a great saving is thus effected, and as the two sorts of bodies are seldom in request at the same time, the wheels can be conveniently made to do double work. A great deal might be written upon carts, as many important problems are involved in the structure of the wheel and axle, the balancing of the cart-body, the arrangement of the load, and the division between weight on the horse's back and draught from the shoulder. The working out of such problems would, however, lead me to devote too much space to this class of farm implements.

IMPLEMENTS FOR PREPARING CROPS FOR MARKETS.

This class includes threshing and all barn implements. The time is hardly yet forgotten when the "flail" was the only machine for separating corn from straw, and when corn-dressing machines were of the most elementary description. I have already referred to Andrew Meikle as the inventor of the Scotch threshing machine, and I may add that Mr. Osley, of Flodden, and Mr. Ilderton, of Alnwick, both of Northumberland, had also devoted their attention and constructed plans for a threshing machine, which was afterwards improved upon by Sir Francis Kinloch, Bart. The principle involved was still that of beating out the corn. The flail was, however, now fixed upon a rotating drum or cylinder, and took the form of a simple raised bar extending along the length of the periphery of the drum. Six of these beaters or bars were fixed upon the drum, which rotated within a concave case, partially surrounding its circumference. If the reader imagines these six beaters whirling round upon the drum at the rate of 800 to 1000 revolutions per minute, within a quarter of an inch of the "concave," he will have no difficulty in understanding how corn is threshed, as it passes through this narrow space. This is all that is required in the act of threshing, and so far it bears a close resemblance to the old system of hand threshing. A threshing machine is, however, a complicated engine, having many functions and many movements. These various functions were formerly performed separately, and hence a machine which is able to at once deliver a sample of corn ready for market is called a "combined" threshing machine, and is either fixed in the buildings or portable, i. e. furnished with wheels. The operations carried on simultaneously in a complete threshing machine are as follows:

1. The separation of corn from straw.
2. Shaking out loose corn which may still be entangled among the straw.
3. Carrying away the straw to a sufficient distance.
4. Winnowing.
5. Hummelling or cutting off the awns from barley.
6. White coating, or removing the white coats or chance-adhering chaff scales from wheat.
7. Screening.
8. Weighing the corn into sacks ready for market.

In order to carry out these numerous requirements, many sheaves, belts, cranks, and links are necessary, and a costly and complicated machine is the result, which is ordinarily worked with an eight to ten horse-power engine. Such implements are to be found on most large farms pretending to be properly furnished; although it is the practice of some farmers to hire portable machines for a few days at a time, and thus thresh their corn when they wish to sell.

Among the principal engineering firms who supply threshing machines, the following may be mentioned: Messrs. Ransome, Sims, and Head, Clayton and Shuttleworth, Marshall and Son, Ruston and Proctor, Gibbons, Nalder and Nalder, Tasker and Sons, and Humphries. Omitting various minor points in which these implements differ from each other, we may fairly divide threshing machines into three sections:

1. Scotch.
2. English portable.
3. English fixed.

The Scotch machine best illustrates Meikle's invention, and is of simpler structure than the two last-named classes. The drum revolves with an upward direction, when viewed from the point at which the corn enters. Threshing is effected between the drum and "drum cover" which surrounds the upper circumference of the drum. The corn and chaff find their way through screens into the "great hopper," and from thence on to the riddles of a winnowing machine. The straw is pushed forward over the screens by means of revolving rakes. The Scotch threshing machine is not adapted for travelling, and is always a fixture. The English threshing machine is much more complicated, and may either be permanently fixed at the buildings, or placed on wheels and used as a portable implement.

The use of portable threshing machines has rendered much possible that formerly would have been impracticable, and has effected a saving in other departments of rural economy besides that peculiarly its own. Thus it has diminished carting, and materially altered the general purposes of farm buildings. The fixed threshing machine will always be the eye or centre of a well-arranged homestead. It is the source of straw—the most bulky and constantly used material at the farmery. The buildings are arranged around it, with due regard to the straw requirements of each; those requiring most being placed nearest to the machine. The engine which drives it is also the source of power for chaff cutting, root pulping, or grinding, and the boiler is a source of heat for steaming. We should make the threshing machine our "point of departure" in constructing a plan of farm buildings.

The introduction of a portable machine and engine changes all this, and favours a totally different system of buildings, namely the "scattered" in place of the "centralized" system. First, the necessity for carting corn home at harvest disappears—the portable engine allowing the threshing to be carried on in the field; secondly, the question arises, Why cart home the straw, when with the help of a shed we could make it into manure, just where the machine left it? This has induced the system of field barns, where corn is threshed, and where beasts are wintered in order to eat it and tread it down into manure. Turnips and food of various sorts find their way to this new home, and, it may be, a cottage is built and a pair of horses maintained for ploughing the surrounding land.

Here, then, are two principles upon which buildings may be erected, springing in a great measure out of the use of portable threshing machines. Let us glance at the relative advantages of each. The centralized homestead is all under the master's eye; it offers a more complete shelter to stock than is possible in isolated sheds and yards; it gives a centralized power which can work all necessary implements, as above explained; it gives also a source of heat from the boiler fires.

The scattered system economises labour at harvest, and reduces the labour of carting both straw and manure. It also enables the farmer to consume his root crops near to the place where they were grown, and to manure land with farmyard dung, which, with a central set of buildings, might have waited for this indulgence for years.

A cottage and stable further economises labour, for fields distant from labourers and horses are expensive to work; and lastly, risk from fire and contagious diseases must be considerably lessened. A good case, therefore, seems to be made out in favour of portable threshing machines and scattered buildings in the case of all wide-lying farms; but for compact, moderate-sized occupations, where no field is above a mile from the homestead, a single well-arranged farmery, with fixed threshing machine and engine, will be preferable. The reader who wishes to study the newest improvements in threshing machines, as well as to thoroughly investigate their relative power and efficacy, will do well to consult the "Report on the Trials of Implements," at Cardiff, by C. G. Roberts, in vol. viii., second series, part ii. of the 'Royal Agricultural Society's Journal.'

It will there be seen that, after repeated trials, Messrs. Marshall, Sons, and Co., of Gainsborough, were awarded the first prize; Messrs. Ransome, Sims, and Head, the second prize; Messrs. Clayton and Shuttleworth, of Lincoln, were highly commended, and Messrs. Ruston, Proctor, and Co., of Lincoln, were commended.

Although threshing machines are now constructed to prepare the sample for market, no barn is complete without an extra corn-dressing machine. Irregularities in speed during threshing, irregularity in rate of feeding, differences in quality between the top and bottom of a rick, all act to prevent perfect uniformity, and hence hand blowing, winnowing, and screening are often still required after corn has passed through a tolerably perfect thresher. Mr. Roberts informs us (Cardiff report) that among the twenty-two implements tried at the last meeting of the Royal Agricultural Society, there were very few that presented any novelty in construction. After thorough trial the following awards were made: J. Cooch, Harlestone, Northants., first prize; Thomas Baker Compton, Newbury, second prize; W. N. Nicholson and Son, Newark, Notts., third prize.

"The very general adoption of finishing threshing machines," writes Mr. C. G. Roberts, "has greatly increased the demand for rotary screens as a part of the machine, but has made it less necessary for each farm to be provided with its own hand-worked screen. As a separate machine, the screen is now perhaps of greater value to the maltster and miller than to the farmer." Still I must rank the corn screen among our farm implements, and I have pleasure in drawing attention to Boby's (of Bury St. Edmunds) new patent self-cleaning corn screen, and his self-acting corn screen, 9*l.* 9*s.* and 8*l.* 10*s.* respectively. W. Rainforth and Son's adjustable rotary corn screen is also a very excellent implement.

IMPLEMENTS FOR PREPARING CROPS FOR HOME CONSUMPTION, OR FOR LIVE STOCK.

These consist of mills for grinding and bruising corn, oilcake crushers, root pulpers, chaff cutters, and cooking apparatus, of various forms. These implements are more used every year over all the south of England. It may be observed generally that the Scotch farmers, even in Lothian, and their brethren in the north of England, still hold pertinaciously to a simple method of feeding cattle and sheep in which these instruments are scarcely required. Where turnips given whole in troughs, and straw given long in racks, almost describes the system of cattle feeding pursued, there seems little room for the pulper and the chaff cutter, although the mill, the oilcake crusher, and the turnip cutter must even here find a place. The case may be thus briefly stated. In North Britain turnips and swedes not only yield much heavier crops than in the south, but are of much higher quality. Cattle and sheep will there make themselves fat much more readily on these esculents than in the south, and hence turnips are looked upon as the cheapest food that can be given. Straw, and especially oat and peas straw, is also much esteemed, and these two substances form in consequence by far the most important materials in stock feeding. In the south of England turnips and swedes are not to be depended upon to yield a heavy crop, and what are grown are of comparatively poor quality. The turnip is by no means the cheapest feeding material, and the consequence is that the farmer welcomes any suggestion for economising it. Hence root pulpers find favour, and the chaff cutter comes into vogue. By their use cattle are made to eat finely-cut straw thoroughly incorporated with a mass of pulped roots, thereby improving both foods. Hay and straw may also be chopped together in any required proportion for all sorts of stock; and further, meal, cattle foods, or crushed cake may be mixed with chaff, in proportions suggested by the chemical composition of each. These implements then enable the grazier to economise his root crop, to feed his straw, and to adopt the suggestions of agricultural chemists with regard to the best proportions of nitrogenous and non-nitrogenous foods.

Steaming and boiling food has had many advocates, but the system does not attract many practical agriculturists. I have myself seen somewhat elaborate conveniences for these purposes neglected on the farms of well-known agriculturists. The best use to make of apparatus for this purpose is that of converting unpalatable foods, such as rapecake and refuse matters, as damaged corn, into a palatable food, and this may often be done with success. Among the best implements for this purpose I would mention that sent out by Messrs. Barford and Perkins, of Peterborough.

No masonry is required, and the range is set down in any convenient shed without danger from fire. It consists of a central furnace and boiler, with pipes passing out on the right and left of the latter. One pipe delivers its steam between the casings of a double-cased iron cauldron, and speedily raises any fluid therein contained to the boiling point. The other pipe delivers its steam into a simple pan, made to contain potatoes, carrots, or turnips. The boiler is provided with a safety valve, and the furnace which is immediately beneath it is so small that economy of fuel is almost compulsory. The whole apparatus may be purchased for 26*l.*, and the expense of coal when divided over a considerable number of cattle and pigs is trifling.

Two more classes of implements still require notice. The first is that which embraces all implements used in the improvement of estates rather than in the ordinary work of cultivation; the other involves the consideration of everything which does not precisely come under any of the heads already discussed. To thoroughly consider these two classes would carry me beyond my allotted limits, for I should be led into subjects more connected with engineering than agriculture on the one hand, and to a somewhat tedious notice of hand tools and out of the way implements on the other. I therefore conclude these remarks with a list of implements required upon a farm supposed to be 500 acres in extent, 400 acres of which are arable and 100 acres permanent pasture land. This farm will further be supposed to be of average fertility, to be of free working soil, and to be managed upon a four-course shift.

Having presupposed the character of the farm, we are in a position to assume the number of teams required, a very necessary assumption when the number of many of the necessary implements is dependent upon it. On such land a team or pair of horses would be able to work 60 acres of arable land, or six teams and an odd horse should suffice. Six teams should be provided with six ploughs, and other implements in proportion; and bearing this in mind we are able to construct the following list:

	£	s.	d.
6 Iron wheel ploughs, at 4*l.* 10*s.*	27	0	0
1 Potato-raising plough, 4*l.* 15*s.*	4	15	0
2 Double mould-board ploughs, at 4*l.* ..	8	0	0
1 Set of ziz-zag drag harrows, 4*l.* 15*s.* ..	4	15	0
1 Set of heavy harrows, 4*l.*	4	0	0
2 Sets of seed harrows, at 3*l.* 10*s.*	7	0	0
1 Set of chain harrows, 4*l.*	4	0	0
1 Coleman's cultivator, 8*l.* 5*s.*	8	5	0
1 Broadshare and cultivator, 10*l.*	10	0	0
1 Crosskill roller, 13*l.*	13	0	0
1 Cambridge roller, 8*l.* 10*s.*	8	10	0
1 Plain iron roller, 8*l.* 10*s.*	8	10	0
1 Light wood roller, 3*l.* 10*s.*	3	10	0
4 Horse hoes (scufflers), at 2*l.* 10*s.*	10	0	0
10 Carts, at 12*l.* 10*s.*, with harvest ladders, extra 2*l.*, 14*l.* 10*s.*	145	0	0
1 Harness, 51*l.* 10*s.*	51	10	0
1 Liquid manure and seed drill, 24*l.*	24	0	0
1 Corn drill, 28*l.* 10*s.*	28	10	0
1 Horse hoe, 18*l.*	18	0	0
1 Broadcast barrow, 3*l.* 5*s.*	3	5	0
1 Reaping machine, 28*l.*	28	0	0
1 Mowing machine, 18*l.*	18	0	0
Carried forward	£437	10	0

	£	s.	d.
Brought forward	437	10	0
2 Horse rakes, at 8*l.*	16	0	0
1 Winnowing machine, 11*l.*	11	0	0
1 Sack holder, 2*l.* 12*s.* 6*d.*	2	12	6
1 Sack barrow, 12*s.* 6*d.*	0	12	6
Lever weighing machine, 6*l.*	6	0	0
2 Sheep turnip cutters, at 5*l.*	10	0	0
2 Cattle " 4*l.* 5*s.*	8	10	0
1 Pulper, 4*l.* 5*s.*	4	5	0
1 Oilcake crusher, 4*l.* 4*s.*	4	4	0
1 Mill, 8*l.* 10*s.*	8	10	0
2 Chaff cutters, at 10*l.* 10*s.*	21	0	0
100 Sacks, at 1*s.* 9*d.*	8	15	0
	£538	19	0

To this list should be added the necessary tools and smaller implements, such as wheelbarrows, corn chests, riddles, forks, rakes, hoes, hedging tools, turnip knives, scythes, hay knife, ropes, straw-rope-twisters, dairy utensils, brushes, spades, shovels, &c., which might cost a sum of say 50*l.* There are also cases in which a set of steam-ploughing machinery, a threshing machine, and portable engine might swell the sum already given to a more than double amount. It is therefore difficult to name a figure which may fairly represent the amount of capital required for implements; but in ordinary cases it has been stated to be about 10 per cent. of the entire capital required; or, in other words, if 6000*l.* is required to enter a 500-acre farm, 600*l.* will be wanted for implements.

RAILWAYS.

By D. Kinnear Clark (Mem. Inst. C.E.).

The earliest railway was no doubt that which is still used by timber cutters in wild countries, who lay down light balks of round timber for the rails, while sticks are formed into rollers as a rude sort of wheel, upon which are placed the massive trees which have to be moved from the forest.

In the mineral districts of England, when coal and iron were dug, and had to be transported seaward down the natural slopes of the country, rollers necessarily gave place to wheels, after the cost of packhorses (though these are employed to this day in Spain) had rendered this mode of conveyance impracticable. Wheels of wood, it was found, were not durable, and they were consequently tyred, or bound with strips of iron on the circumference. It was a continuous process of trial and failure. More than two hundred years ago, Master Beaumont, "a gentleman of great ingenuity and rare parts, adventured into our mines [near Newcastle], with his thirty thousand pounds, who brought with him many new engines not known then in those parts, as the art to boore with iron rods, to try the deepnesse and thicknesse of the coale; rare engines to draw water out of the pits; waggons with one horse to carry down coales from the pits to the staythes on the river, &c.

Within a few years he consumed all his money, and rode home upon his light horse."

In 1676, railways consisted of two rails of wood, which were laid straight and parallel on the level surface; thus making a way or movable road between the mine and the seaport, by leave and permission of the intermediate proprietors, and hence called "way-leaves." On these, carts with two wheels were not convenient, and the way'n, wain, wagon, or waggon, was made "with four rollers fitting those rails, whereby the carriage was so easy, that one horse would draw down four or five chaldrons of coals, and was an immense benefit to the coal merchant." The planks forming the path for the wheels were, as a matter of course, connected by cross timbers, and thus a space was enclosed, from which apparently comes the term "rail"; or, possibly, the resemblance of the timbers in form to the rails of a post-and-rail enclosure may have supplied the name.

The coarse construction of the wheels caused a rapid abrasion of the timber, and it became a common practice to nail down strips of iron on the surface of the ascending inclines of the road, where the draught was increased by the wear of the timber. Then the practice obtained of fixing down double rails—a supporting rail below, and a wearing rail upon it, to be taken up and replaced when too much worn. The rapid wear of the timber led to the construction of cast-iron rails, one hundred years later, in 1776, to replace the wooden ones, and being limited in width, they were formed with a continuous flange or ledge on their inner edge, to keep the wheels on the track. The roads were then called "tram-roads," after the waggons or "trams" which were run upon them. But the tram-road was liable to be covered with dust and gravel, and so, in 1789, cast-iron "edge rails" were laid down, so called because they presented a narrow edge, without any ledge, for the wheels to run upon; the guiding ledge, in fact, being applied round the edges of the wheels, forming flanged wheels, instead of flanged rails. The rails were carried in cast-iron chairs, which were spiked down to stone blocks, or "sleepers," in the ground. But, in the course of time, they proved to be liable to fracture under the loaded waggons and the locomotive engines by which they were drawn, and accordingly, in 1820, the "fish-belly" rail, which was of rolled wrought iron, was introduced. It was similar in form to the edge rail, but rolled in continuous lengths, embracing a number of spans, with stiffening ledges or flanges on the under side. This form of rail grew in favour, and was adopted in the construction of the Liverpool and Manchester Railway in 1829. The rail weighed 33 lb. per yard of its length, and was laid in cast-iron chairs, spiked down to square stone blocks placed at distances of 3 feet apart. It was fortunate for the country that this, the first important line of railway, had been entrusted to the consummate practical skill and experience of George Stephenson. The Liverpool and Manchester Railway, now a portion of the London and North-Western system, will descend to succeeding ages as a monument to his memory; and it happily served as a model railway for those which more immediately succeeded it. George Stephenson's son, Robert, and his pupils, were entrusted with the execution of several of the most important lines, and they were attended with similar successful results to those which characterized the first railway constructed for passenger traffic.

The edge rail and the flanged wheel were happily matched, and constitute essentially the mechanical idea of modern railways—the basis of the whole system.

As in all other roads, so in railways, the first consideration is the use to which it is to be applied, and the weight on the wheels which are to run over it. A common mistake has been committed in making the road—the permanent way, as it is called, in contradistinction from the temporary rails used by the contractors—too weak. This has been largely the case with American roads. One of their earliest forms of rail consisted of a flat bar of iron, half an inch thick, spiked down to longitudinal timbers. In the process of running the trains the iron became curved, the spikes loosened, and the ends of the bars turned up, so as to be called "snakes' heads." Occasionally they pierced the bottoms of the carriages, and injured passengers; and it was no uncommon thing to hear passengers speculate by which line they should travel, as showing fewest snakes' heads.

The next point is that the road should be thoroughly well drained, that all rainwater falling on the line may have facility to run off the surface without soaking in, and that all running water crossing the line may be provided with culverts to pass below it. The sleepers should be bedded on porous stone or gravel, constituting the ballast, without any clay or other impervious matter in it. The rails should be stiff, both vertically and laterally, so that they should neither yield to the lurches of the engine and the train, nor to the heavy loads carried on the wheels. The earliest rails made in England were carefully made of good tough lasting iron, and have been known to last over twenty-five years. But the quality has degenerated, owing to the presence of competition amongst manufacturers, and the low prices, so that many recent iron rails have been worn out in from five to ten years. The acceleration of wear is, nevertheless, to a material extent due also to the increase of traffic, and particularly to the heavier loads placed on wheels than formerly. A locomotive driving wheel may bear on the rail with a pressure of at least 5 tons, whilst it has been proved that the actual area of the surface of contact below the wheel and the rail does not exceed a quarter of a square inch. The load is therefore equivalent to a pressure of 20 tons per square inch on the rail, and it is well understood that wrought iron cannot permanently resist such excessively concentrated pressure.

Engineers endeavour so to plan the works of a railway, that the earth to be excavated from the high ground shall be equal to the embankments to be formed in the valleys, so as to effect a redistribution of material rather than its removal, and thus arrive at the desired result in the most economical manner. A wise discretion has to be exercised in laying out the route of a new railway—neither, on the one extreme, to divert it hither and thither to avoid every difficulty, or to embrace every eligible district on the route; nor, on the other, to carry it with absolute directness, as the Emperor Nicholas willed when he laid down the route of the St. Petersburgh and Moscow Railway, on the map of Russia, by drawing a mathematically straight line between the two capitals.

The fundamental datum for the construction of a railway is the gauge or distance apart of the two parallel bars which form the line of rails. The gauge, strictly considered, is simply a correlative of the width between the wheels. The first consideration is, or should be, the gauge of the wheels, and that of the rails follows as a matter of course. Two leading gauges have obtained in England, known as the broad and the narrow gauges, respectively 7 feet and 4 feet 8½ inches wide, although the narrow gauge has practically superseded the broad one. But why a fractional measure should have been selected has puzzled many people. The fact seems to be that the track of the original carts or trams, of 5 feet outside the wheels, was taken as a standard for the gauge of rails, which were measured outside also. The width of the rails on the top, being originally 1¾ inch, this would give 3½ inches for the rails, leaving 4 feet 8½ inches exactly for the inside measure or gauge. When, subsequently, the rails were widened to get broader bearings and greater strength, the additional width was necessarily added on the outside, the gauge remaining the same, to suit the flanges of the wheels. The gauge of railways in Ireland is uniformly 5 feet 3 inches, being 6½ inches wider than the English gauge. The European gauge is, for the most part, the same as the English; but the Spanish gauge is wider, being 5 feet 6 inches, causing a break at the French frontier: commercially inconvenient, but supposed to be expedient as a security against a sudden French invasion. The gauge of railways in India, also, is 5 feet 6 inches; the American gauge is various—from 4 feet 8½ inches to 6 feet; and as some of the gauges differ only about an inch, rolling stock is occasionally interchanged, and of course runs tight and loose.

Within the last few years, some engineers have broken away from the traditional gauge. The Festiniog Railway, in Wales, built originally to carry slates from the quarry to the port, has one of only 1 foot 11½ inches—probably the narrowest in the world. In Sweden, the later railways have been constructed to a 3 feet 6 inch gauge; and in India, it has been decided to construct new branch lines to a gauge of one mètre, or 3 feet 3⅜ inches. The partisans of the newer narrow-gauge system, of course, argue that it is less expensive to construct and maintain than the standard gauge system. The advantages have been made the subject of much special pleading, and have been greatly exaggerated.

The earthworks of a railway are the foundation and support of the superstructure, and, as such, should be uniformly firm, and carefully considered with respect to material, preparation, form, and drainage; of liberal width, with easy lateral slopes, ample ballast, and thorough drainage. The ordinary formation of a *cutting* in earth, for two lines of rail, is 33 feet wide, bounded by the side drains, for carrying off rainwater or melted snow from the ballast. Beyond the side drains, the slopes ascend to the natural surface of the ground, rising 1 foot for 2 feet horizontally. Upon the formation level the ballast is deposited 2 feet in depth, and about 3 feet wide at the top, leaving ample margin on each side, beyond the outer rails. The two lines of rails are separated by a space 6 feet in clear width, commonly known as the "six foot." The sleepers and chairs are buried in the ballast, and the rails rise two or three inches above the level of it, so that they may remain clear of gravel or other superficial obstructions. The total width of the cutting at the base is 42 feet. Embankments are the reverse of cuttings, being elevated above the surface of the ground, whilst cuttings are sunk below. They are regulated in outline by the same general dimensions as cuttings, which are frequently as deep as from 50 to 100 feet below the natural surface, while embankments are occasionally as high above it. The heaviest cutting on the London and Birmingham Railway is at Tring, 2½ miles long, averaging 40 feet deep, the greatest depth being 60 feet. The Winchburgh cutting on the North British Railway, between Edinburgh and Glasgow, is 4 miles long, and from 25 to 60 feet deep, through solid whinstone rock; and it is succeeded by an embankment a mile and a half long and 60 feet high, which leads to a stone viaduct half a mile long and 80 feet high. In crossing Chat Moss, 4 miles across, on the Liverpool and Manchester Railway, George Stephenson, as he could not find a bottom, floated the railway upon the moss. There was no alternative, for cattle could not stand on it, and a bar of iron would sink in it. The achievement of crossing the moss, unprecedented at the time, afforded an unequivocal proof of that admirable self-reliance which never contemplates failure.

The effect produced by the construction of a railway is by no means limited to the abstraction of a strip of land. The value of property adjoining the spot selected for a station is generally very largely increased, but residential damages are sometimes considerable. The Birmingham and Gloucester Railway ran through 15 feet of cutting near the town of Cheltenham. Trial shafts were sunk, which were stopped at 8 feet of depth by quicksands. The quicksands were tapped, a channel being lowered a few inches at a time, so as to drain the whole, and with as little rush and disturbance as possible. The unstable sand was then gradually dried, and became as sound a substratum as could be desired. But all the wells in the town had been dried in the operation, and it was necessary to sink every one of them from 3 feet to 6 or 8 feet. It may be mentioned that in the same locality, north of the hill containing the quicksand, and alongside the little stream of the Chelt, ran a belt of bog, a swampy, quaking morass; a plan was adopted for crossing it, which reminds one of the exploit of George Stephenson at Chat Moss. The whole surface of the field within the railway fences was levelled to the surface of the water, and covered with wattled hurdles. Turf was spread over them, and a bed of sand 2 feet in depth was laid over the turf; the surface thus made bore the railway without any difficulty.

In passing through the consecutive cuttings of a railway, travellers usually consider that the cuttings made through rock must have been desperate undertakings, much more costly than cuttings through clay. Their relative costs, however, do not greatly differ; for not only does the vertical rock cutting require a less quantity of excavation than the wide yawning earth cutting of an equal depth with extended slopes, but the rock cutting is not subject to the expensive slips which sometimes happen to the other. It is usual to make a cutting at any depth less than 60 feet below the surface of the ground; for greater depths it is generally less costly to tunnel. The Kilsby tunnel, on the London and North-Western Railway, is 160 feet below the surface, 1 mile 3 furlongs in length, 30 feet wide, and 30 feet high, and has two wide air-shafts 60 feet in diameter, descending from the surface to admit light, as well as air, to enable the engine-drivers to see the rails from end to end. It cost nearly 300,000*l*., or 125*l*. per yard running, a charge which was forced upon the Company in consequence of the opposition of the inhabitants of Northampton, who strenuously resisted the original design of the engineer, Robert Stephenson, to carry the railway through that town, by which two objects would have been fulfilled—the travelling necessities of the town, and the avoidance of the tunnel. But the inhabitants, by their opposition, drove the line to a distance of five miles away, never anticipating that railways would or could supersede mail and stage coaches, but regarding them as "but smoky substitutes for canals." The famous Box tunnel, on the Great Western Railway, was another difficult and expensive work, 70 feet below the surface, 1¾ mile long, and with eleven air-shafts. The longest railway tunnel in England is the Stand Edge tunnel, on the London and North-Western Railway, towards Huddersfield; its length being 3 miles and 60 yards. But the more recently completed tunnel under Mont Cenis, crossing the Alps, overshadows all others, as yet constructed, in magnitude and importance. It is the completing link of the Victor Emmanuel Railway, which puts France in direct railway communication with Italy, and places Turin within eighteen hours' journey of Paris. The tunnel passes under the Col de Fréjus, about 18 miles west of the actual Mont Cenis, and is nearly 8 miles in length. In section, it is elliptical, being 25 feet 3½ inches wide at the base, 26 feet 2¾ inches wide at the broadest part, and 24 feet 7¼ inches high. At the north end it is constructed 11¾ inches higher, and more elliptical in form than in the body, to enable it to resist the greater stress caused by a different inclination of the strata. At the south end it is built of stone at the sides, and of brick at the upper part; at the north end it is entirely of stone. The line rises from both ends towards the middle of the tunnel, on an incline rising 1 in 45½ feet horizontal from the north, and rising 1 in 2000 feet from the south. The tunnel was excavated from the solid rock by the aid of compressed-air machinery, which was employed for driving *the boring* tool, to drill holes in the rock for the re*ception of* charges of gunpowder, to blow out the material. By thus employing compressed air, which was of five atmospheres pressure, instead of steam, advantage was taken of the opportunity to maintain a supply of fresh air for the workmen in the tunnel, and for carrying off the gaseous products of the explosions. The progress made in cutting the tunnel, after the machinery and all arrangements were matured, averaged about 1 mètre, or 40 inches per day at each end.

The St. Gothard tunnel through the Alps, now (1876) in course of construction, will be, when completed, of still greater magnitude than the Mont Cenis tunnel. It was projected to complete the link which is to connect the Swiss system of railways and the railways of Upper Italy, in the valley of the Ticino. The length will be 9¼ miles. The section of the tunnel is the same as that of the Mont Cenis. The excavation is conducted entirely by means of mechanical perforators driven by means of compressed air. The construction of the tunnel was commenced in August, 1872; it is now more than one-third constructed, and is extended at the rate of 8 yards per day for both ends; and it is expected that the tunnel will be completed by August, 1879.

There are about 80 miles of tunnels in Great Britain, which have been constructed at an average cost of 45*l.* per yard running, or about 80,000*l.* per lineal mile.

Ordinary road bridges are usually constructed of brick or stone over or under a railway, as the case may be. If built across a cutting, over the railways, the foundations are laid in steps on the solid natural earth. But, on the contrary, if the bridge is built under the railways, in continuation of an embankment, the foundations are built up square from the solid ground. Large bridges have been built of timber and of cast iron, as well as of brick and stone, but those materials have generally been superseded by wrought iron, forming girder bridges constructed either of plates or of bars, or a combination of plates and bars. Lofty bridges and viaducts are now built either entirely of wrought iron for the piers and the spans, or with piers of stone and wrought-iron girders, either straight and parallel-sided, or arched.

There are many stone viaducts of great length, of which the one over the Almond Valley, on the North British Railway, is 720 yards long (nearly half a mile), and has 36 segmental arches, each 75 feet in span. The Ballochmyle viaduct, over the river Ayr, on the Glasgow and South-Western Railway, has a semicircular arch of 180 feet in span—the largest span of railway masonry in Great Britain, or probably anywhere—with six smaller arches of 50 feet span. The only other stone bridge of greater span is the common-road bridge over the Dee at Chester, of 200 feet span.

The Congleton viaduct, on the line between Manchester and Birmingham, is perhaps the longest viaduct of magnitude in England. It is of stone, and is 1026 yards, or more than half a mile in length, and 106 feet high. It cost 113,000*l.*, being at the rate of 112*l.* per yard running. The Avon viaduct, on the Midland Railway, of brick, is 240 yards long, with eleven arches of 50 feet span, and cost 14,000*l.*, or 60*l.* per yard running. The Britannia Tubular Bridge, across the Menai Straits, is 616 yards, or more than a third of a mile, long, and 104 feet high. It cost 600,000*l.*, or

974*l.* per yard running. On the different lines entering London, and other large towns, there are miles of viaducts of moderate height, stretching as far as the eye can reach. It is estimated that there are 80 miles of railway viaducts in the United Kingdom.

The great theatres of the operations of railways, preliminary and subsequent to the transport of passengers and goods from place to place, are the stations, which are both terminal and intermediate. The vast buildings and their dependencies, which constitute a chief terminal station of a great line of railway, consist of three principal sections: 1st, the passenger station, appropriated for the general offices of the Company, and for the embarkment and disembarkment of passengers; 2nd, the goods station, appropriated to the reception, loading, unloading, and discharge of goods and live-stock carried by railway; 3rd, the depôts for locomotives, carriages, and waggons, where the rolling stock reposes, and is cleaned, examined, and repaired. It may be added, the carriages and waggons, when in good order, are stored, when not in active use, in or near the passenger and goods stations; while at many intermediate stations similar arrangements on a smaller scale are made.

The stations for passengers and goods are generally in different positions—sometimes distant from each other. The passenger station abuts on the main line, or forms the natural terminus of the railway, at a place as near as can conveniently be obtained to the centre of the population from which the passenger traffic is derived; the terminal goods station is approached by a siding or fork let off from the main line at some *point short of the* passenger station. At Liverpool, for example, the main line of the railway leads to the passenger depôt by a tunnel under the streets, and terminates near the centre of the town. The branch leading to the goods station is conducted by a separate tunnel to the docks and quays, where the goods are received directly from the shipping upon the rails, and reciprocally from the rails to the shipping. Every effort should be made to secure for a terminus, or other station, a position on the surface of the ground rather than on an embankment, or on a viaduct, or in a cutting, facility of access in all directions from the surrounding districts, with good roads, being indispensable.

The St. Pancras terminal station, in London, of the Midland Railway, is said to have the largest passenger shed in the world. The platforms and rails are covered by an iron roof with a single span of 240 feet, and a length of 689 feet 4 inches. It covers ten lines of rails. The total cost of the roof, excluding screens, was 53,483*l.* The annexed table shows, for comparison, the spans and costs of the roofs of different railway stations—the cost being given per square of 100 superficial feet:

Name of Station.	Span of Roof.	Cost per Square, exclusive of Gables.		
	feet.	£	s.	d.
New Street, Birmingham ..	211			
Charing Cross	166	34	0	0
Cannon Street	190	43	10	0
Lime Street, Liverpool	212	30	0	0
Victoria	120	27	13	4
St. Pancras	240	31	11	0

The extent of accommodation required in sidings forms a large item of expenditure. On the main line of the London and North-Western Railway, between London and Birmingham, 113 miles long, there were, twenty years ago, 53 miles of siding of single line, equal to nearly half the length of the railway. On the whole system there was 1 mile of sidings for every 5½ miles of railway, the stations averaging a distance of 4 miles apart. On the Great Northern Railway, at King's Cross station, there are 18½ miles of sidings; and on the whole line there is probably 1 mile of siding for every 3 of railway, the stations being at an average distance of 4 miles apart. It would thus appear that the Great Northern Railway Company forestalled the demand for the siding room, which, in the experience of the older lines, was ascertained to be necessary.

The formation of the line to the permanent way has already been noticed. The ends of the rails are united by two fish-plates, one on each side of the rails, bolted together with four bolts and nuts. The rails are keyed into cast-iron chairs by oaken keys, and the chairs are spiked down to transverse wooden sleepers. This is the ordinary method of fixing rails. Cast-iron sleepers are used in hot climates, and in situations where wooden sleepers fail. They are of the form of shallow bells, which rest mouth downwards in the soil, and have chairs cast on their upper surfaces for the reception of the rails. Apertures are formed in the upper surface of these sleepers, through which the ballast may be introduced for packing them.

Rails are of various forms, the most common being the double-headed, the Vignoles or flat-footed, and the Brunel or bridge-rails. The double-headed rail, so called because it consists of a vertical rail with two heads, or widened portions at top and bottom, is usually from 2¼ to 2½ inches broad at the head, and 5 inches deep; the flat-footed rail has only one head or bearing surface, and the foot is made flat for the purpose of resting direct upon the sleepers, and being spiked to them. It is much used in America and on the continent of Europe. The bridge-rail is used on the Great Western Railway and in Ireland. It is on longitudinal or continuous sleepers, and is much employed on bridges. Rails, whatever the section, may be said generally to follow these dimensions: height, 4½ to 5 inches; breadth of table or wearing surface, 2¼ to 2½ inches. The weight of rails is varied according to the loads which they have to carry—from 40 lb. to 80 lb. per lineal yard. A very common weight is 75 lb. per yard. It is of course understood that rails are always made parallel-sided. They are ordinarily of wrought iron rolled; but within the last few years rails made of Bessemer steel have been laid down to some extent, and are particularly to be recommended when the traffic is heavy and frequent, on account of their durability being greater than that of iron rails, variously estimated at from six to fifteen times as much.

The use of switches and crossings is to form a communication between one line of rails and another. They are usually constructed of ordinary rails, and carried in cast-iron chairs specially formed to receive them, and spiked down to sleepers. The two switch-rails forming the points are movable, and are worked by rods to which heavy weights are attached, the function of the latter being to retain the points in one position, and to act as a self-acting adjustment in restoring them, after having been shifted for the passage of an engine or a train. It is of great importance that the switches should be kept always in their proper position, so that they may not endanger a train passing over them by throwing it off the rails. "Facing points" are such as are laid on the main line, so as to face or point towards advancing trains; they have caused many accidents, and so dangerous have they been found to be, particularly on high-speed railways, that in general they are absolutely forbidden at all except terminal stations and at intermediate stations where all trains are timed to stop; at junctions with other lines they are of course unavoidable.

Turntables are of two classes, first, for turning carriages and waggons; second, for engines and tenders. They are most useful at terminal stations, and indeed at all stations, for the marshalling of trains. Turntables of the first class are ordinarily of cast iron, about 14 feet to 15 feet in diameter, and consist of a revolving table with crossed lines of rails on it turning on a central pivot and on rollers at the circumference, which are upheld by a cast-iron base on a firm foundation.

For turning engines and tenders together, a much longer table is required, 40 feet in length or so. A common form of table consists of two longitudinal balks of timber, or wrought-iron girders, which carry a line of rails, framed together with iron beams, by means of which the central part is supported on a pivot, and the extremities on a pair of rollers at each end. The table revolves in a pit about 4 feet deep, on a large circular race of cast iron, bedded on a firm foundation, to carry the rollers, and the motive force is applied by means of driving gear.

Traversers are a convenient substitute for turntables, particularly for working a number of parallel lines of rails. A traverser is simply a low rectangular frame, made with two overhung rails to receive a carriage or a waggon, and movable on rollers across the lines of rail, so as to change the vehicle from any one line of rail to another.

Water-cranes are erected at convenient spots for supplying water to the locomotive tenders or tanks. They commonly consist of an upright column containing within it the supply pipe, which is connected at the upper end with a horizontal swing pipe, free to revolve round the column, and to be swung out of the way when not in use. It is sufficiently long to reach over the middle of the line of rails, and has a leathern hose attached to it to direct the stream of water into the tender.

With regard to signals, the semaphore is now very generally employed, and has in a great measure superseded the disc as a means of signalling. But the railway companies do not all work by the same code. One manager uses it to give two signals, and another *to give* three; a third will have an auxiliary or distant signal, placed at 500 yards or 600 yards from the station, to act as a repeating signal, his neighbour perhaps preferring to use it only as a caution. In the employment of the semaphore, the arm is turned straight out, perpendicular to the post, as the signal of danger; diagonally downwards, at an angle of 45°, as a signal of caution; and it is turned home, disappearing within the post, when the line is all clear for the approach of the train, though in many cases it is never turned lower down than at the point of caution. Distant signals have but one arm, as they act only upon trains approaching in one direction. Station signals have two arms, right and left, to direct the trains arriving in either direction. To work the signals to the best advantage, for the utmost degree of security, there must be a clear definition of the duties of the attendants upon signals, and they should be strictly enforced; the most suitable men should be selected, adequately remunerated, and provided with convenient, warm, and well-fitted lodges, with ample window-space, within which they may keep a constant watch over the line without exposure to weather. It is now the practice at terminal stations, and at principal junctions, to erect a signal-house in an elevated position, to enable the signalmen to overlook the whole of the station and its approaches. The signals as well as the switches are all worked from the signal-house by means of levers ranged in a row, each one connected by rods and bellcranks with its special pair of switches. By thus concentrating the manipulation of the signals and points, a large number of lines of rail may be worked, particularly when the signals are interlocked with the points. At Charing Cross station, for example, there are three signal-posts and twelve semaphores employed in the direction of the traffic, over four lines of rails on the bridge, ramifying into nine lines within the station. There are thirty-two pairs of switches, interlocked, when required, with signals, making from 80 to 110 movements per hour, worked by two men, under the orders of an agent who communicates with them by means of telegraphic apparatus. At the Cannon Street station there is an establishment of twenty-four semaphores arranged on four posts, of which eight arms are for regulating the passage of trains outwards, and sixteen arms for trains inwards, from and to the station, with nine lines of rails. The signal-house contains sixty-seven levers, of which thirty-seven are used for working signals and thirty for points. The signals lock the points and each other. In the course of a single working day, 775 trains have passed under the signal bridge; in the course of thirty-five minutes, one morning, thirty-five trains were signalled in and out of the station. Two men are employed to work the levers.

On railways of great traffic, the block system of working signals is becoming generally practised. The object of this system is to secure an interval of space between trains following each other on the same line of rails; the signals are closed against all trains approaching on a line of rail, until the train which last passed the signalling station has passed clear of the *interval* between this station and the next. For the purpose of working the block system, therefore, there must be frequent signal stations provided with means of communication with each other. Experience has proved that this system is compatible with the highest rates of speed. On some railways, where the block system is worked over the entire line, the speed of some of the trains is from 50 to 60 miles per hour. There are many single lines where this system has been found indispensable for the safety of the traffic. The interlocking system, already referred to, by which the points and the signals are caused to work in concert, may be most advantageously worked in conjunction with the block system. Railway companies have during the last five years (1875) paid 2,348,000*l.* in compensation for injury to passengers and goods, and therefore have a direct pecuniary interest in rendering their lines safe.

It is hardly necessary to observe, that a locomotive engine differs in many particulars from other steam engines. The machine, as its name imports, is intended for locomotion; and it must carry along with it the fuel and water which are necessary to maintain its action. The condition of locomotion at high velocity in so weighty a mass as the lightest and most compact locomotive must be, implies, moreover, a subjection to violent strains and shocks, which must be provided for.

The year 1829 is famous in the annals of railways for two things, the opening of the Liverpool and Manchester Railway—the type and forerunner of modern railways; and the invention and construction of the first high-speed locomotive of the standard modern type; the railway, by George Stephenson; the locomotive by his son, Robert Stephenson. This engine, the 'Rocket,' was made under competition for the Liverpool and Manchester Railway, and it gained the prize for lightness, power, and speed, awarded by the directors. Its weight was 4 tons 5 cwt.; the tender following it, with coal and water, weighed 3 tons 4 cwt.; and two loaded carriages drawn by it on the trial weighed 9 tons 11 cwt. The gross weight of the engine, tender, and train amounted to 17 tons. It ran at an average speed of 14 miles per hour, the greatest velocity attained being 29 miles per hour; and it evaporated 18¼ cubic feet, or 114 gallons of water per hour.

This engine comprised the three elements of efficiency of the modern locomotive:—1st, the internal water-surrounded firebox, together with the multitubular flue in the boiler, being a number of small tubes, in place of one large tube, by which the hot products of combustion were subdivided, and the heating surface for the evaporation of water very much increased; 2nd, the blast-pipe, from which the waste steam of the engine was exhausted up the chimney; 3rd, the direct connection of the steam cylinders, two in number, on each side of the engine, with the driving or propelling wheels on one axle. The subdivision of the large single flue then in general use in locomotives, into a number of small tubes, proved of marvellous advantage in accelerating the rate of absorption of heat by the water, and the generation of steam, without adding to the size or weight of the boiler. But the evaporating tubes would have been of but little avail practically for increasing the supply of steam, had they not been complemented by the blast-pipe, which, ejecting the steam from the engine, after it had done its work in the cylinders, straight up the chimney, excited a strong draft through the boiler, and caused a brisk and rapid combustion of fuel and generation of heat. The heat was absorbed with proportional rapidity through the newly-applied heating tubes. The blast-pipe in connection with the multitubular flue vastly increased the range and capacity of the locomotive; and these, taken together with the direct connection of the steam cylinders to one axle and pair of wheels, made a new and original machine. The 'Rocket' is now to be seen at the Patent Museum, South Kensington.

The 'Rocket,' subsequently, drew an average gross load of 40 tons behind the tender, at 13·3 miles per hour. The old engines on the Killingworth railway could only average 6 miles per hour with 50 tons.

The way having been pointed out, constructors on all sides worked, each in his own fashion, at the locomotive; and for many years the practice of builders was moulded into two types of engine, both of which had two cylinders placed horizontally inside the smoke-box, under the chimney. The types were distinguished by the number of wheels. In one there were six wheels, of which one pair was placed behind the boiler; in the other there were only four wheels, placed under the barrel of the boiler, having the firebox overhung. Experience has demonstrated the disadvantage of an overhung mass with a too limited base on wheels, in the four-wheeled engine when running at high speed; and now it is the general practice to apply six wheels at least to all ordinary locomotive stock. As the tractive power of the locomotive is rendered available by the adhesion or grip of the driving wheels on the rails, the grip of two or even three pairs of wheels is made available for adhesion in engines designed to draw heavy trains, by coupling rods, which are attached to cranks fixed on the wheels or their axles. The four or six wheels thus connected are bound to revolve together; and thus it is that a train load which it would be impossible for an engine, otherwise sufficiently powerful, to move, with only one pair of driven wheels, can be readily moved by the same engine when its wheels are coupled together. In respect of tractive power, therefore, there are three recognized classes of engines: 1st. Engines with one pair of driving or driven wheels, known as quick passenger engines. 2nd. Engines with two pairs of driving wheels, for taking heavy passenger trains, or light goods trains, or a mixed train consisting of passenger carriages and goods waggons, known as four-coupled or mixed engines. 3rd. Engines with three pairs of driving wheels, for taking goods trains, known as six-coupled goods engines. There are many varieties of these engines. As they are, most of them at least, supplied with a tender to carry fuel and water, it is necessary to add that some engines are so constructed as to carry their fuel and water on their own *frames*, dispensing with tenders, and called tank engines. These are useful for short runs, or running with "short trains," and for marshalling and shunting trains at stations.

Locomotive engines, again, are distinguished by the position of the steam cylinders, inside or outside the framing and the wheels. Inside-cylinder locomotives have the cylinders within the framing, under the boiler, with the main driving axle cranked at two points to receive the power from the two cylinders. Outside-cylinder locomotives have the cylinders placed external to the framing, and connected, not to the axle, which is straight, but to crank-pins fixed between the spokes of the wheels, in connection with the naves. In these engines, the general contour of the cylinders is visible externally at the fore-end of the engine.

The tenders of locomotives are placed on four or six wheels, according to the gross load, and to the choice of the designer; and they are supplied with powerful brakes, worked by screws, with blocks of wood to be pressed upon each wheel when the brake is applied. A water tank forms the upper part of the tender, and usually occupies the two sides and the hind end, in the form of a horse-shoe, capable of holding from 800 to 1200 gallons, or even 1500 gallons. In the hollow of the shoe the fuel is deposited, of which a full charge may weigh 30 cwt., or 2 tons.

Within the last few years, a change in the disposition of the wheels, so as to facilitate the passage of locomotives on the curved parts of railways, has been introduced, following the practice in America. Instead of the front pair of wheels, a "bogie" is placed under the engine, resting on four wheels—being in fact a four-wheeled truck—connected with the body of the engine by a central pivot, upon which the bogie is free to turn round to the right or the left and follow the windings of the railway. By this means, the resistance of curves to engines is much less than when they have rigidly parallel axles. When the bogie is applied in front, the engine has two pairs of wheels coupled together behind, making altogether an eight-wheeled engine. The North London and the Metropolitan (London) Railways are worked exclusively with bogie-engines; as are also the passenger trains in the United States.

The earliest four-wheeled locomotives constructed by Robert Stephenson and Co., Newcastle-on-Tyne, as an article of regular manufacture, weighed 9 tons, "with steam up," having fuel, and water in the boiler. The six-wheeled engines which followed weighed 11½ tons. A passenger locomotive of the present time weighs from 26 to 30 tons in working order; a goods locomotive, from 27 to 35 tons; and the tenders, from 10 to 11 tons empty, or from 18 to 20 tons when filled with fuel and water. Tank locomotives for ordinary traffic weigh from 27 to 43 tons; and those specially designed for working on steep gradients from 40 to 49 tons, in working order.

The pressure of steam now commonly employed in locomotives is from 100 lb. to 140 lb. per square inch, though in the days of the earliest modern locomotives 50 lb. was considered ample pressure.

The ruling dimensions of locomotives are those of the steam cylinders and the driving wheels. In passenger engines the cylinders are usually 16 inches in diameter, and have a stroke of 24 inches; the driving wheels are from 6 to 7 feet in diameter, or occasionally 7 feet 6 inches. In one or two modern instances the wheels have been made 8 feet in diameter. For goods locomotives, on the contrary, the cylinders are generally larger, and the wheels smaller, than those of passenger engines. For steep-gradient locomotives, the cylinders are frequently from 18 to 20 inches in diameter, whilst the wheels are only 4 feet in diameter.

The area of surface in the locomotive boiler exposed to the action of the fire and the products of combustion for the evaporation of water varies from 800 to 1200 square feet. The extraordinary compactness of the boiler may be appreciated if it be compared with an ordinary Lancashire boiler, containing 770 square feet of heating surface. The locomotive boiler is comprised within a horizontal space of 4 feet wide and 15 or 16 feet long, whilst the Lancashire boiler with less surface is 7 feet in diameter and 28 feet long. The compactness of the locomotive boiler is to be ascribed to the use of the small flue-tubes, which are only $1\frac{7}{8}$ or 2 inches in diameter.

Railway carriages are divided into three classes, to suit the various requirements of travellers: some preferring seclusion, ease, luxury, high speed; others preferring society and economy, with moderate comfort and moderate speed; others looking to economy simply. These can be easily recognized as first, second, and third class passengers, respectively. The first class of carriages are cushioned all over; the second class, partially, but in general sufficiently padded or cushioned; the third class, left hard and square, as they come from the carpenter, with excessive means of ventilation, evincing a brutal policy to drive passengers to travel by the higher classes. On the Midland Railway, second class carriages are not used, but only the two classes of first and third. It is desirable that the different classes should be uniform in external dimensions, that they may be carried on underframes of one common design and dimensions for all the classes; thus promoting uniformity of stock, for the sake of economy in working and repairs. The most recent dimensions of the bodies of carriages for main lines are, for the length 21 feet, width from 7 feet 6 inches to 8 feet, and about 6 feet 6 inches high, externally; divided into three compartments for first-class carriages, each 7 feet long, while the four compartments for second and third class are 5 feet 3 inches each in length. The first class are seated for six persons in each compartment, in all eighteen seats; though, by dispensing with the partitions or "elbow-rests," they receive eight, or four on each side, amounting in all to twenty-four persons. The second and third classes are regulated to hold five persons on each side, or ten in each compartment, making forty in all. Taking the inside width of the carriage at six inches less than the width outside, the allowance in width of seat is from 17 to 18 inches per passenger, which is liberal *when* compared with the minimum fixed by Act of

Parliament at 16 inches. But even the largest of these widths is scarcely sufficient for comfortable repose.

With regard to the underframes of carriages, they are most commonly of hard wood, necessarily very strongly constructed, to enable them to withstand the shocks and other strains to which they are subject. Heavy buffing springs have in general been applied, placed within and across the frame to resist concussions, and also to act as drawsprings. But these are being displaced by indiarubber springs, which are light, compact, and strong. Of these, Spencer's indiarubber springs have been found to work with great success, being durable, strong, and elastic. Carriages were originally placed on four wheels; subsequently six wheels were applied, but besides adding to the weight, they were found to increase the resistance of the train; and thus, ultimately, practice reverted to four wheels. The axles are placed at from 10 to 12 feet apart between the centres. The wheels were formerly 3 feet in diameter, but they have been and are now generally made 3 feet 6 inches.

The weight of railway carriages has gradually increased from 3¼ tons, the weight of the early carriages, to from 5½ to 6 tons in present practice.

The special carriage stock of the North London Railway is worthy of notice. The body of the first class is 27 feet 1¾ inches in length and 8 feet wide; it is divided into four compartments, and holds thirty-two passengers. The second class body is 27 feet 11 inches long, with five compartments, holding in all fifty passengers. Until recently, there was no third class. The carriages run on four wheels, 3 feet 6 inches in diameter, and the axles are placed at a distance of 15 feet apart. The weight of these carriages is from 7¾ to 8 tons.

Mr. Fowler has recently designed carriages for the New South Wales Railway, 35 feet 2 inches in length, and 7 feet 9 inches in width. The first class is divided into three compartments, of which the two extreme ones are 7 feet 1 inch long, and the middle compartment is 21 feet long, as a saloon; it holds in all thirty passengers. The second class contains six compartments, to hold fifty passengers, and one compartment for the guard. The underframes are made of angle-iron, and run on four pairs of wheels 3 feet 6 inches in diameter, of which the distance apart of the extreme axles is 23 feet 6 inches, or two-thirds of the length of the frame. The extreme axles are movable laterally and radially, so as to radiate to the curves, and obviate the resistance offered by curves to wheels on rigidly parallel axles.

Besides the three classes of passenger carriages, the carriage-train stock consists of composite carriages, luggage brake-vans, horse-boxes, and carriage-trucks. To this may be added the mail carriage, or travelling post-office, and the mail van or tender. Sleeping carriages have recently been introduced on most of the northern lines, attached to the night trains between Glasgow, Edinburgh, and London. They are 30 feet in length, 7 feet 6 inches wide, and 6 feet 10 inches high inside. A second-class compartment is at one end of the carriage, and a luggage compartment at the other end. The intermediate space is occupied by the first-class compartments, each about 8 feet in length, with a short lobby, supplied with toilette conveniences. A cistern is fitted to the roof to supply water. By day the carriage is used as a day carriage, and it is easily arranged for sleeping by folding up three of the seats in each first-class compartment, and pulling the back forward, thus forming a comfortable bed, furnished with a pillow.

Colonel W. D. Mann has introduced, from America, sleeping carriages, weighing 13 tons, to accommodate twenty-two persons. They are 40 feet long and 9 feet 6 inches broad; and beds for eighteen persons can be made up. The Pullman palace car has been for some years in vogue in the United States. It is a huge structure, 60 feet long and 10 feet wide; it weighs 36 tons, and can carry forty-eight persons, for whom sleeping accommodation is provided. Pullman cars run on the Midland Railway.

The argument for uniformity of waggon stock is still stronger than that for carriages, for waggons are much more numerous than carriages. One of the greatest engineering evils inflicted in earlier times upon railway companies arose from the want of arrangement or consultation between the officers of different lines, in order to consider the question, common to all, as to the best plan and construction of vehicle to be used by them. The result was that several companies built classes of stock, which were not suited to work conjointly the traffic of their own and other lines. Amongst the early contributors to the concoction of the railway waggon, were to be found the great carriers, their agents, road contractors, farmers, builders, wheelwrights, salesmen, graziers, timber merchants, and others whose occupations and opinions gave birth to a wide diversity of practice.

Goods-train stock has, however, gradually settled down into consistency; it comprises covered waggons, open or box waggons, high-sided round-ended waggons, coal waggons, cattle and sheep waggons, brake-vans, and other special waggons for particular goods, as salt, coke, gunpowder, and lime. Open waggons weigh about 4 or 5 tons, and carry 8 or 10 tons of goods. Covered waggons weigh from 4 to 5 tons, and carry from 6 to 8 tons, according to the bulk of the goods.

The cost of a first-class carriage to hold eighteen passengers is about 340*l.*, while an ordinary open goods waggon costs 80*l.*

The average speed of express trains, including stoppages, is from 36 to 42 miles per hour, while that of parliamentary trains, stopping at all the stations, varies from 17 to 21 miles. The average maximum or full speed on the Great Northern Railway is 47 miles per hour; but a speed of 62 miles is occasionally attained. On the Great Western Railway a speed of 65 miles per hour is sometimes reached.

The ordinary average speed of goods trains, including all stoppages, varies from 10 to 18 miles per hour, the actual running speed being from 15 to 25 miles. The very large goods traffic of the London and North-Western and Great Northern Railways is moved faster where it has to be kept clear of the passenger traffic; the mean speed, including stoppages, is from 15 to 20 miles per hour, and the actual running speed is from 30 to 35 miles per hour.

If an engine, weighing with its tender 32 tons, takes, say, forty loaded carriages, weighing, say, 200 tons, at a speed of 20 miles per hour, on a level, the loads which it could take, if it exerted the same tractive force at higher speeds, would be less, in the following proportions:

ON A LEVEL.

					Tons.
At 20	miles per hour,	40	carriages,	weighing	290
30	„	30	„	„	220
40	„	21	„	„	160
50	„	15	„	„	115
60	„	11	„	„	85

The influence of inclines or gradients on the performance of an engine is important. Suppose the same engine and tender to take a train of 56 loaded carriages, weighing 420 tons gross, at 20 miles per hour on a level, it would only draw, exerting the same tractive force, and at the same speed, the following loads on the following inclines, ascending:

AT TWENTY MILES PER HOUR.

					Tons.
Level,		56	carriages,	weighing	420
Incline	1 in 600,	45	„	„	340
„	1 „ 300,	36	„	„	270
„	1 „ 150,	27	„	„	200
„	1 „ 100,	20	„	„	150
„	1 „ 75,	16	„	„	120
„	1 „ 50,	12	„	„	90
„	1 „ 40,	9	„	„	65
„	1 „ 30,	6	„	„	45
„	1 „ 20,	3	„	„	24
„	1 „ 10,	nil.			nil.

The resistance of trains amounts to from 8 to 10 lb. per ton weight of train on a level line at low speed. It increases rapidly with the speed, and at 60 miles per hour it amounts to about 45 lb. per ton.

A goods engine is capable, when working full power, of exerting a tractive force from 10,000 to 12,000 lb., or about 5 tons.

According to the returns of the Board of Trade, the length of railways in the United Kingdom, at December 31st, 1874, was as follows:

	Miles.
Constructed in England and Wales ..	11,622
" Scotland	2,700
" Ireland	2,127
Total for the United Kingdom ..	16,449

These railways are owned by 583 companies, possessing an average length of line of 28 miles. But the whole property is actually worked by 125 companies, to whom the others have leased their lines, and who work them with their own. Of these 125 companies, the following are the numbers for the three divisions of the United Kingdom, together with the respective lengths of line under management:

	Companies.	Average Length worked by each Company.
		miles.
England and Wales	94	124
Scotland	7	386
Ireland	24	88
Totals	125	132

It would appear from this, that amalgamation and concentration of management have made less progress in Ireland than in England and Scotland. The greatest mileage of railway belonging to one company is that of the London and North-Western, which is 1600 miles. The following is a selection of the longest and shortest railways worked by single companies:

ENGLAND.	Miles worked.
London and North-Western	1600
Great Western	1532
North-Eastern	1386
Midland	1114
Dowlais	2
SCOTLAND.	
North British	847
Caledonian	826
City of Glasgow Union	4
IRELAND.	
Great Southern and Western	465
Midland Great Western	409
Belfast Central	4

In the beginning of the year 1875, the capital raised for the construction of railways in the United Kingdom amounted to 610 millions sterling, or about 37,000*l.* per mile constructed.

Of the total capital raised, about 74 per cent. is in stock and shares, and 26 per cent. in loans and debentures.

The following is an approximate analysis of the average cost of the railways as they stood in 1871.

	Per Mile.		Per Cent.
Law and parliamentary expenses ..	£2,000	or	5·5
Land and compensation	7,000	„	19·5
Works of construction and stations complete	18,000	„	50
Locomotion and carrying stock ..	3,000	„	8
Interest on stock, discounts, bonuses, dividends from capital, contingencies	6,000	„	17
Total cost	£36,000	„	100

It is remarkable that the actual cost of the railways with rolling stock should be only 58 per cent. of the total cost, or 21,000*l.* per mile; law and parliamentary expenses cost 2000*l.* per mile. A multitude of laws have been placed upon the Statute book which will excite the wonder of future generations, the London and North-Western Railway alone being regulated by more than two hundred different Acts. The expenses of obtaining an Act of Parliament have been excessive. The adherence to useless and expensive forms by parliamentary committees, in what are called the Standing Orders, or general regulations for the observance of promoters of railway bills, and the opposition of others, have been among the chief causes of excessive expenditure. Mr. Stephenson used to quote an instance showing how Parliament entailed expense upon railway companies by the system complained of. The Trent Valley Railway was, under other titles, originally proposed in 1836. It was, however, thrown out by the Standing Orders Committee in consequence of a barn, of the value of 10*l.*, which was shown upon the general plan, though it was not exhibited upon an enlarged sheet. In 1840, the line again went before Parliament. It was opposed by the Grand Junction Railway Company, now a part of the London and North-Western. No fewer than four hundred and fifty allegations were made against it before the sub-Committee on Standing Orders, which was engaged twenty-two days in considering these objections. The Committee ultimately reported that four or five of the allegations were proved, but they nevertheless allowed the bill to proceed. It was read a second time, and passed into Committee, by whom it was under consideration for sixty-three days, and ultimately Parliament was prorogued before the report could be made. It may be questioned whether the ultimate cost of constructing the whole line was very much more than the amount expended in obtaining permission to make it.

Then, as to land and compensation, the Eastern Counties Railway had, up to 1846, paid not less than 809,950*l.* on that account, equal to about 12,000*l.* per mile. The land purchased by the London and Birmingham and Great Western Railways cost above 6300*l.* per mile.

But the most conspicuous example in recent times, which overshadows all others, of excessive expenditure in parliamentary litigation, as well as in land and compensation, is supplied in the history of the Great Northern Railway Company. The preliminary expenses for surveys, notices to landowners, &c., commenced in 1844, and the bill was introduced into the House of Commons in 1845, when it was opposed by the London and North-Western, Eastern Counties, and Midland Railways. It was further opposed by two other schemes successively, called the London and York, and the Direct Northern. The contest lasted eighty-two days before the House of Commons, more than half the time having been consumed by opposition to the bill. The bill was allowed to stand over till the next year (1846), when it began, before the Committee of the House of Lords, at the point where it left off in the Lower House in 1845, on account of the magnitude of the case. The bill was before the Upper House for three or four months, and in the same year (1846) it was granted. The promoters of rival projects were bought off, and all their expenses paid, including the costs of the opposition of the neighbouring lines already named, before the Great Northern bill was passed; and the preliminary expenses, comprising the whole expenditure of every kind up to the passing of the bill, was 590,355*l.*, more than half a million sterling, incurred at the end of two years of litigation. Subsequently to the passing of the Act, an additional sum of 172,722*l.* was expended for "law and engineering expenses in Parliament" to December 31st, 1857, which was spent almost wholly in obtaining leave from Parliament to make various alterations. Thus, it would appear, a sum total of 763,077*l.*—above three-quarters of a million—was spent as parliamentary charges for obtaining leave to construct 245 miles, being at the rate of 3115*l.* per mile.

The payments made during the same period, by the Great Northern Railway Company, for land and compensation amounted to 1,901,371*l*., or nearly two millions sterling, at the rate of 7760*l*. per mile. The parliamentary, and land and compensation charges together made a sum of 2,664,448*l*., or 10,875*l*. per mile of the original line. The total payments on capital account were 11,299,300*l*.; and of this amount those items constitute the formidable proportion of 23½ per cent., being nearly one-fourth of the capital forestalled before ground was broken.

The particulars of the Peebles Railway may now be quoted, in contrast to those of other lines, as a perfect example of economical construction and legitimate expenditure. The railway, now worked by the North British Railway Company, is a single line, 15¾ miles in length, from Peebles station to the point of junction with the North British Railway at Eskbank station, 8 miles from Edinburgh. There was no opposition to the project, and the landowners agreed to give the land required at thirty-five years' purchase of the agricultural value, the value and the severance damage being fixed by arbitration; nor did the turnpike-road trustees make any claim for damages. The Act was passed in July, 1853, and the actual cost of obtaining it was only 650*l*., no fees to counsel having been found necessary. The total parliamentary expenses, up to the obtaining of the Act, was 1569*l*.; but further expenses were incurred in 1857, in applying for power to raise new capital. The charges for land and compensation amounted to 21,222*l*., or to 1131*l*. per mile. Seven stations, with approaches, including Peebles station, averaging one for every 2¾ miles, were built at an average cost of about 1200*l.* each. The works were constructed for about 3600*l.* per mile, and the locomotive and carrying stock cost about 1000*l.* per mile. The railway was opened in July, 1855, two years after the passing of the Act. The total cost, at the end of 1858, amounted to 6688*l.* per mile.

In the year 1874, there were conveyed on the railways of the United Kingdom a total of 477,840,411 passengers, in addition to whom there were 493,957 season-ticket holders. Of that number, there were of first, second, and third class, the following proportions:

			Per Cent.
First class	39,274,759	or	8·2
Second class	72,262,963	„	15·2
Third class	366,302,689	„	76·7
	477,840,411	„	100·0

Showing, in round numbers, that the first class are only 8 per cent. of the whole number; second class, 15 per cent.; and third class, 77 per cent. If these proportions be compared with those of the year 1857, fourteen years earlier, it is clearly apparent that both first and second class passengers are now much less numerous, and the third class more so than at that time, thus:

	1874.	1857.
	per cent.	per cent.
First class	8·2	13·4
Second class	15·2	30·4
Third class	76·7	56·2
	100·0	100·0

The number of miles run by passenger trains, in 1874, were as follows:

	Miles run.	Per Mile of Railway.
England	81,408,225	7,005
Scotland	9,897,601	3,666
Ireland	8,444,127	3,970
Total	96,749,953	5,880

This shows a total mileage by passenger trains of, say, 97 millions of miles, in 1874; being nearly 6000 per mile of railway for the year, representing seventeen trains on an average passing over each mile daily.

The receipts for passenger traffic in 1871 were as follows:

	£		Per Cent.
First class	4,499,351	or	18·0
Second class	4,099,181	,,	16·5
Third class	12,346,605	,,	49·6
Season tickets	1,069,181	,,	4·3
Excess fares	2,904		
Excess luggage, parcels, carriages, horses, dogs, &c. ..	2,220,200	,,	9·0
Mails	656,193	,,	2·6
	£24,893,615	,,	100·0

The average fare paid by each passenger was 10·5 pence. In 1870 it was rather more than a shilling; and the smaller average fare in 1874 points to the greater use of third-class carriages. In 1857, thirteen years earlier, the receipts per passenger averaged eighteen pence.

In 1874 upwards of 110 million tons of minerals, and 78 million tons of general merchandise, were conveyed on the railways of the United Kingdom, in transporting which the goods trains ran 100 millions of miles, for which 32 millions sterling were received.

The total number of miles run by passenger trains and goods trains was as follows:

	Miles.
Passenger trains	96,749,953
Goods trains	100,025,939
Mixed trains	3,708,371
	200,484,263

Here there is a remarkable nearness to equality between the miles run by passenger trains and by goods trains, each about 100 millions of miles.

The average total receipts were about 5*s.* 11*d.* per mile run by trains.

The expenses were nearly 33 millions sterling, and the net receipts amounted to more than 26½ millions for payment of interest on preference shares and loans, and dividends on ordinary share capital. The expenses amount to 55 per cent. of the gross receipts.

The working expenses, expressed in pence per mile run by trains, are as follows:

	Pence.	
Maintenance of way	6·55	
Locomotive powers	8·99	
Maintenance of carriages and waggons	2·54	
Traffic department	9·04	
General charges	1·17	
Total direct expenses		28·30

Brought forward		28·30
Contingent expenses:	Pence.	
Rates and taxes	1·18	
Government duty	·60	
Compensation	·60	
Legal and parliamentary	·31	
Steamboat, &c.	·96	
Miscellaneous	·57	
Total contingent expenses		4·20
Total working expenditure per train-mile run		32·50

Showing that the direct expenses, or such as are incurred in the actual management and working of the traffic, amount to 2*s.* 4¼*d.* per mile run by trains; and that the contingent expenses amount to 4¼*d.* per mile. The total expenses of all kinds amount to, say, 2*s.* 8½*d.* per mile run by trains.

Of the railways in all parts of the world there were, in 1873–74, a total of 168,140 miles in operation.

Accidents happen on railways every year, attended with loss of life or bodily injury, and it is a matter of the utmost moment to investigate the causes of these, to reduce their number and violence to a minimum, and, if possible, to eliminate them from railway experience. That they can be altogether avoided, no one will maintain, so long as humanity is weak and liable to error; but those who are best qualified to judge do not hesitate to affirm that their number may be greatly diminished. Mr. F. J. Bramwell, an excellent authority, gives the following analysis of accidents on British railways in 1870–73, showing the percentage of each kind:

	Per Cent.
Collisions of various kinds	58·7
Trains turned on to wrong lines, "or split"	12·0
Leaving the rails	9·2
Defects in the rolling stock	9·2
On inclines	4·6
Entering stations at too high a speed	1·8
Miscellaneous	4·5
	100·0

	Per Year.
Deaths of passengers from causes beyond their own control	35·5
Journeys, exclusive of season-ticket holders	397,478,249

	Per Death.
Journeys	11,000,000

The comparatively small number of lives that are lost on the railways, in the midst of this enormous traffic, is a fact that says a great deal for the good management of the lines, and proves that, upon the whole, there is no kind of vehicle safer than the railway carriage. As to the origin of the accidents, the chief causes are want of care, or mistakes of officers or servants, alone or in combination with defective signal and switch arrangements, and want of telegraphic communication, or of a system of securing intervals between trains. In addition to these causes, there are imperfect regulations, defective discipline, foggy weather, defective accommodation for traffic, defective construction, and insufficient brake power.

The Board of Trade's Inspectors of Railways strongly advocate the adoption by all railways of the principle of securing intervals of space between all trains instead of intervals of time, in order to the avoidance of accidents. This may be effected by means of the telegraph, worked not only at the railway stations but also at intermediate signal stations—a system which has been introduced on several lines. On the southern portion of the London and North-Western Railway, a signal apparatus is stationed at every 2½ miles, and every train as it comes upon a fresh length of 2½ miles is telegraphed forward to the next station of the series; and when it leaves that length its passage forward is telegraphed back to the station behind. By this means they have the power of preventing trains from being within 2½ miles of each other, be their speed or irregularity what it may. Such a system as this (called the "block system" of working) conduces very materially to the safety of a line, and inspires great confidence into the men whose duty it is to work the traffic. Indeed, the metropolitan lines, and other lines of crowded traffic, could not be worked safely for a day without such a system. During fog, the telegraph apparatus is of inestimable utility in conjunction with the use of fog signals, which are fixed to the rails, and discharged with a loud report by the engine in passing over them. During fog, however, it is advisable that the speed of the trains should be reduced, as the danger is then so much greater. As a further means of avoiding accidents, the interlocking of signals and points, already described, has been of essential service. In the present condition of railways, with junctions of great and constant traffic, and trains continually crossing each other in all directions, the signalmen could not in some cases work safely for a single hour without the protection of such apparatus; while they are enabled by its aid to go on working from year to year without accident in the most difficult situations, as, for instance, at the Charing Cross and Cannon Street stations of the South-Eastern Railway. Perfect brakes are also indisputably promotive of safety in working traffic and in compensation for unavoidable irregularities. With the usual amount of braking power, a train at 50 miles per hour may not be stopped within 900 yards or 1200 yards. An instantaneous brake is not, of course, what is wanted; on the contrary, a length of 200 yards appears to be the shortest desirable space within which a train at 50 miles or 60 miles per hour should be stopped so that the process of retardation should not be accompanied by the risk of carriages overriding each other, or of violence to the passengers; and this has been accomplished by means of several systems of brake in which the braking action is applied to each carriage. Steam brakes applied to the locomotives, and extended to the tenders, and even to the brake-vans, have been found beneficial, and capable of stopping a train within half the usual distance.

The general adoption of a simple method of communication between the guard and the driver of a train in motion is a desideratum. There are various plans obvious and sufficient enough, but it would appear that, to ensure their adoption by all railway companies, *legislative* interference must be invoked.

TRAMWAYS.

By D. Kinnear Clark (Mem. Inst. C.E.).

We have seen that tramways were constructed at least two hundred years ago, in the north of England, for carrying coal and iron from the mines to the coast. Superseded by railways, they were cast into the shade and lost sight of, but now there is a reaction in their favour, though a form of tramway very different and very superior to the old system is employed. The modern tramway is, in fact, a compromise between streets and railways, and is in reality a street railway.

The first tramway, or horse-railway, for the conveyance of passengers, is believed to be that which was opened in 1821, between the towns of Gloucester and Cheltenham. The modern tramway, consisting of iron rails, on which vehicles with flanged wheels are run, originated in America, where it appears to have been introduced in New York, and laid down by M. Loubat, a French engineer, on a system of his own, about 1850, after which tramways were generally adopted in the States. In 1853–54, M. Loubat laid down a piece of tramway in Paris, from the Place de la Concorde to Passy, probably the first piece of horse-railway in Europe. In 1857, Mr. Train made proposals for laying down tramways in some of the metropolitan thoroughfares, and in some of the provincial towns of England. The first tramway in England on Mr. Train's system, introduced from America, was laid down in Birkenhead, and was opened in August, 1860. A section of tramway on the same system was laid down on the Bayswater Road, in 1861, between the Marble Arch and Notting-hill Gate. His mode of construction was known as the Philadelphia system. The rail was a broad slab of wrought iron, having a raised tread rolled on the outer edge, on which the wheels of the cars ran, whilst the flat portions, at a lower level, were to be run upon by ordinary vehicles. It was found, however, in London, as in Philadelphia, that the difference of levels was so great an inconvenience to cross or oblique traffic, that the rails were taken up after a short trial. The failure of Train's line acted as a damper to tramway enterprise, and it was only in 1870 and 1871 that tramways were permanently adopted and constructed in London. There are upwards of 42 miles of tramway opened for traffic in the metropolis; and tramways are now in operation in Birmingham, Liverpool, Leeds, Edinburgh, Glasgow, Dundee, Plymouth, Devonport, Cardiff, Dublin, and Belfast. They are also in operation in most of the large cities in the United States and of Canada, and also in St. Petersburgh, Vienna, Brussels, Copenhagen, Paris, Lisbon, and Buenos Ayres.

The system of construction of tramways is very simple: a foundation of concrete is laid in the ground, upon which is bedded the wooden sleepers, which run longitudinally, for carrying the rails. The rails are of wrought iron, and weigh generally about 60 lb. per yard. They are carefully fitted and secured by spikes to the sleepers, and are formed with ledges to embrace the sleeper at both sides. The upper surface of the rail is flat, and, when in place, it is flush with the ordinary surface of the roadway, so as to avoid causing any obstruction to the free passage of ordinary wheel traffic over the line. A groove is rolled in the upper surface of the rail, to receive the flanges of the wheels of the cars, by which they are kept in the track.

The cars are of a plain rectangular form, having an extreme length of about 25 feet; of this length, the body of the car occupies 16 feet, and it is 7 feet 4 inches in width. Two platforms are provided, one at each end, for the entrance and egress of passengers. The cars hold twenty persons inside and twenty-two on the roof, to which access is provided by light wrought-iron flights of steps. The wheels are 2 feet 6 inches in diameter, in two pairs, placed about 6 feet apart between the centres of the axles. The weight of an empty car is from 2 tons 4 cwt. to 2 tons 10 cwt.; and, loaded, 5 tons. It is drawn by two horses.

The tramways are very successful as financial concerns. The London and the Dublin tramways pay 10 per cent. on their capital. With pitched paving between the rails and extended in width to 18 inches on each side of the line, the London tramways cost from 4000*l*. to 6000*l*. per mile of single line, according to the price of materials; or from 8000*l*. to 12,000*l*. per mile of double line. For the supply of carriages or "cars," the cost is 1200*l*. per mile; and for horses, allowing ten horses per car, 1000*l*. per mile. Thus the total cost per mile of double line has been from 10,000*l*. to 14,000*l*.

The earnings on lines in full operation amount to from 100*l.* to 140*l.* per mile per week; and per passenger to from 2*d.* to 2¼*d.*

Horse power for traction will no doubt be ultimately superseded by steam power, in the working out and application of which there is scope for nice design and adaptation. A practically successful steam-car has yet to be designed. In Mr. Grantham's steam-car there are two small upright boilers, which are closeted between the passengers, one on each side of the car, for supplying steam to work a pair of small engines under the floor. A car propelled by compressed air has recently (January, 1876) been started on the Paris tramways. A supply of compressed air of twenty-five or thirty atmospheres of pressure is carried in a number of sheet-iron cylindrical reservoirs beneath the floor, from which air is taken to drive the car by means of cylinders and gearing similar to those of a locomotive. The car runs without noise.

The cost above cited of the construction and equipment—so unassuming and unobtrusive—appears unexpectedly high. The earnings are, however, high also. The average earnings on the railways of the United Kingdom do not exceed 38*l.* per mile per week. The earnings of the London and North-Western Railway are 106*l.* per mile per week, which is less than the lowest recorded earnings in the latest published accounts of the London tramways. The Dublin tramways earned, in the last half-year of 1872, 100*l.* per mile per week.

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